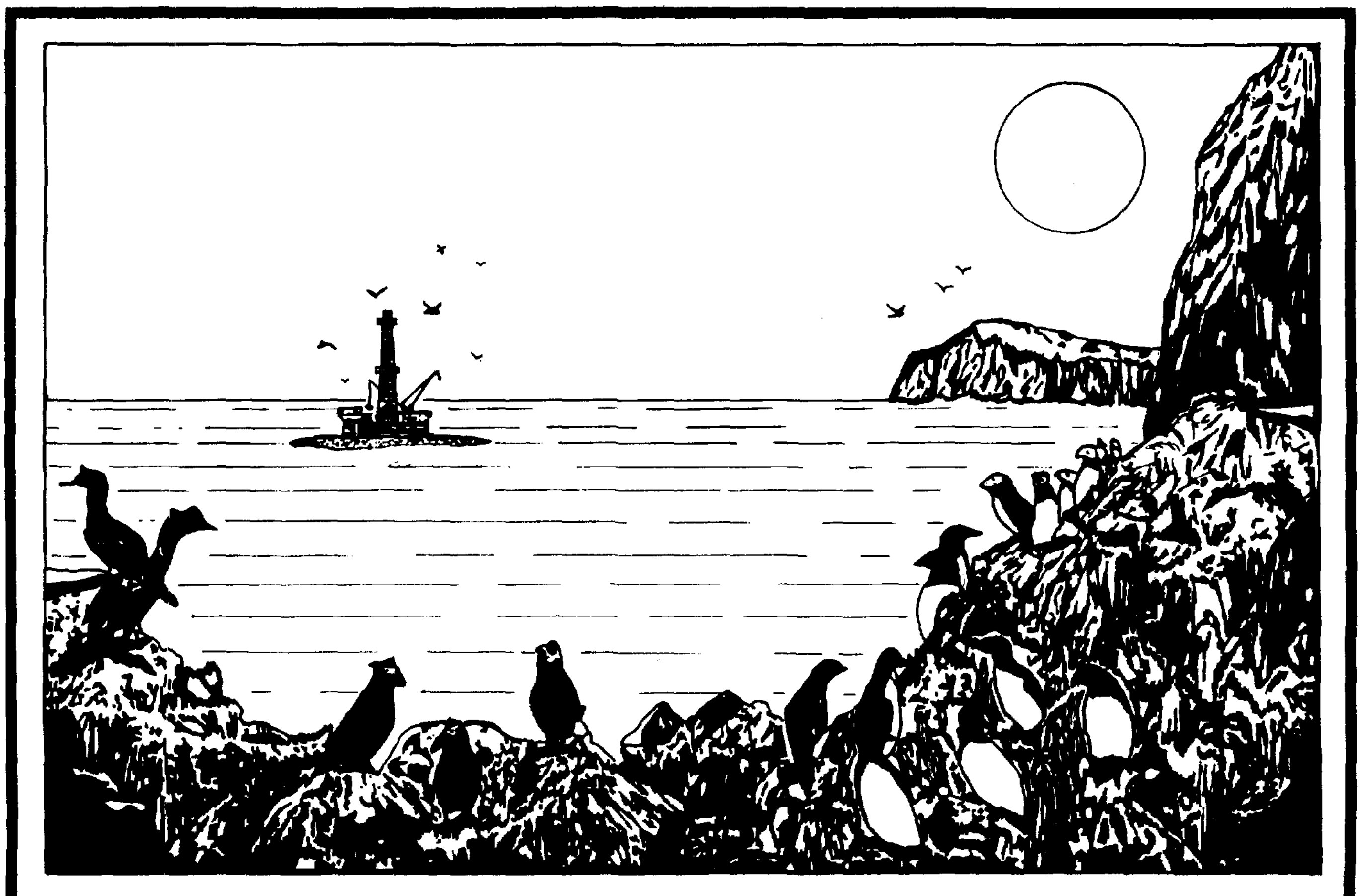
HD9567.N67S7 1981

Recommendations for Minimizing the Impacts of Hydrocarbon Development on the Fish, Wildlife, and Aquatic Plant Resources of the Northern Bering Sea and Norton Sound



Habitat Division
Alaska Department of Fish and Game
1981

Funding for this project was provided by a Section 308d Coastal Energy Impact Grant from the National Oceanic and Atmospheric Administration of the Department of Commerce through the Coastal Energy Impact Program and administered by the Alaska Department of Community and Regional Affairs.

RECOMMENDATIONS FOR MINIMIZING THE IMPACTS OF HYDROCARBON DEVELOPMENT ON THE FISH, WILDLIFE, AND AQUATIC PLANT RESOURCES OF THE NORTHERN BERING SEA AND NORTON SOUND

Prepared by:

Suzanne J. Starr, CEIP Project Coordinator
Mark N. Kuwada, Habitat Biologist
Lance L. Trasky, M/CHM Project Leader

Marine/Coastal Habitat Management
Habitat Division
Alaska Department of Fish and Game
Anchorage, Alaska 99502

For:

Alaska Department of Community and Regional Affairs
Coastal Energy Impact Program
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

June 1981

ACKNOWLEDGEMENTS

We gratefully acknowledge those staff members who assisted in the preparation of this publication: Sharon Wilson as principal typist; Vikki Benner, Lee Rogers, Iris Frank, Nell Tsacrios, Joyce Villard, and Bonnie Herbold-Miller for assisting with the typing and with preparation of graphics. Special thanks are extended to Robin Mooring for her preparation of the maps accompanying this report and for providing assistance beyond her cartographic duties with typing and editing.

We would also like to thank David Burbank of the Marine and Coastal Habitat Management staff for providing administrative assistance.

Appreciation is extended to the staff of the Nome office of the Alaska Department of Fish and Game, to Caleb Pungowiyi of Kawerak Inc., and to other individuals in the State, Federal, and Private sectors who offered their knowledge and assistance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

INTRODUCTION

Background

In September of 1982 a Federal outer continental shelf oil and gas lease sale is scheduled for the northern Bering Sea-Norton Sound region. A State lease sale previously scheduled for late - 1981 is currently being coordinated to occur simultaneously with the Federal sale, with a second State sale subsequently planned for 1983. Because of the magnitude of these sales and the fact that fish and wildlife resources in the northern Bering Sea-Norton Sound region are of considerable economic and social importance to the State of Alaska; the Department of Fish and Game has conducted an analysis of potential effects arising from oil and gas related activities and their impacts on fish and wildlife resources. It has been shown that, in addition to oil pollution, fish and wildlife resources can be impacted by drilling muds and cuttings; noise and disturbance; dredging and filling, gravel mining, and gravel islands; shoreline alteration; formation waters; cooling waters and water withdrawal; secondary development; harvest interference; and air pollution.

It is also apparent that the current level of knowledge regarding abundance and distribution of fish and wildlife resources in areas where such impacts are likely to occur is not sufficiently detailed to be used effectively as a means of protecting these resources. The Alaska Department of Fish and Game has concluded that if a major oil field were discovered, development might occur so rapidly and on such a large scale, that the Department would not have sufficient time or resources to deal with all of the activities through the normal project by project permit review process. The only effective means of mitigating potential impacts appears to be to anticipate potential problems and provide industry planners and resource managers with comprehensive information on project design and siting criteria before extensive planning or any significant amount of construction occurs. The early availability of this type of information should, moreover, greatly simplify and expedite the process of siting and designing facilities while minimizing the impacts on fish and wildlife resources.

In requesting a section 308(d) Coastal Energy Impact Grant from the Department of Community and Regional Affairs, the Department of Fish and Game chose Norton Sound and the northern Bering Sea as a region warranting study for a variety of reasons. First, there are no immediate insurmountable hazards associated with drilling in this region. Unlike other offshore areas such as the Beaufort and Chukchi seas, or Navarin and St. George basins, problems associated with shifting multi-year pack ice, or excessively deep water depths are expected to be minimized. Second, this region supports an abundant number and diverse array of species. Areas such as the Yukon Delta, the Bering Strait, St. Lawrence Island and the wetlands encircling the perimeter of Norton Sound are critically important toward maintaining the continued viability of an immense number of animals. Third, subsistence values are extremely high in this region. Historic and present day subsistence utilization patterns attest to the fact that the majority of people in this region are socially and economically dependent on recurrent harvests of fish and wildlife resources. Beyond being just a source of food, these resources provide the basis for an entire lifestyle which revolves around the seasonal appearance of harvestable species. Finally, very little infra-structure is available with which to absorb the full developmental impacts of a moderate to high find oil and gas discovery. Components of secondary development such as deep water port facilities, treatment plants, roads, and transmission corridors, all have the potential to disrupt fish and wildlife populations or harvest activities, either during their initial construction or in their eventual operation.

The object of the Department's Coastal Energy Impact Study is to 1) develop a comprehensive inventory of fish, wildlife, and aquatic plant resources in the coastal and offshore marine waters of the northern Bering Sea-Norton Sound region, 2) assess and quantify the effects of major activities associated with oil and gas development on fish and wildlife populations, and 3) develop guidelines and recommendations for preventing, reducing, or ameliorating fish, wildlife, aquatic plant, and habitat losses due to hydrocarbon exploration, development and production. In this respect, the Department's northern Bering Sea-Norton Sound Coastal Energy Impact study is specifically designed to accomplish two goals: 1) minimize the impacts of offshore energy development and related onshore activities on subsistence, commercial and recreational fish and wildlife resources, and 2) expedite the processing of permits for activities associated with oil and gas development in order to allow development to proceed at the most rapid pace and lowest economic cost commensurate with 1).

By providing industry planners with information on critical or sensitive fish and wildlife habitats, and the most effective means of mitigating impacts early in the exploration phase, subsequent activities may be planned and facilities located in order to avoid conflicts with renewable resources, which could result in extended permitting or legal delays. Simultaneously, renewable resource managers and permitting agencies will be provided with accurate information on 1) the abundance and distribution of important fish and wildlife resources; 2) the impacts of various activities; and 3) the most effective means of mitigating impacts of activities associated with oil and gas development. This information should enable the permitter to expeditiously determine the effects of an activity on fish and wildlife resources, thereby allowing him to provide effective protection to these resources while minimizing the required time to issue a permit.

This study was conducted in three phases: 1) all of the available information on fish and wildlife abundance, distribution, and life history was collected and depicted graphically on maps and, where necessary, supplemented with a narrative description; 2) the effects of the major activities associated with oil and gas development on fish and wildlife resources were identified and assessed through extensive literature research; and 3) mitigatory measures were developed to protect important fish and wildlife populations from the adverse effects of oil and gas related activities. The Department's Coastal Energy Impact Project is presented in three parts: 1) a narrative impact report; 2) resource inventory maps of fish, wildlife, and aquatic plants in Norton Sound and the northern Bering Sea; and 3) impact maps showing the relative sensitivity of fish and wildlife habitats to oil and gas disturbances. These three parts are described in more detail below:

1. The narrative impact report includes: 1) a description of the study area; 2) a description of the five phases of oil and gas development; 3) a description of oil and gas activities leading to environmental disturbances; 4) a discussion of the sources and biological effects of disturbances caused by oil and gas activities; 5) the sensitivities of areas in the northern Bering Sea-Norton Sound region to disturbances; and 6) recommendations for mitigating the adverse developmental impacts on fish, wildlife, and aquatic plant resources.

2. Eight resource inventory maps accompany this report. Map 1 shows ice conditions during winter periods. Map 2 identifies winds, ocean currents, and coastal marine and terrestrial habitats. Maps 3 through 7 depict the known concentrations of benthic invertebrates, anadromous and marine fish, marine and terrestrial mammals, and birds. Map 8 shows major subsistence, commercial and recreational harvest areas. The inventory maps represent a synthesis of data from Alaska Department of Fish and Game field biologists, regional Native associations, the Outer Continental Shelf Environmental Assessment Program (OCSEAP), U.S. Fish and Wildlife studies, the Alaska Department of Fish and Game Fisheries Atlas, Wildlife and Habitat books, annual reports, and other resource publications. These maps were not intended to show general distribution, but rather to

depict where concentrations of fish and wildlife resources are found in the northern Bering Sea-Norton Sound region. Population and harvest estimates were included when this information was available. Each map was reviewed by those biologists and other resource specialists who had originally provided the information depicted.

3. The nine impact maps depict the relative biological sensitivities of fish and wildlife habitats in the northern Bering Sea-Norton Sound in relation to the following oil and gas disturbances: site preparation; noise and disturbance; drilling muds and cuttings; oil pollution; dredging and filling, gravel mining, and gravel islands; shoreline alteration; formation waters; cooling waters, and water withdrawal; interference with subsistence, commercial, and sport harvests. Sensitivity designations were applied by project biologists after reviewing species concentrations and determining their vulnerability to the above stated impacts. These designations may be subject to revision should new data warrant such action.

In all cases, an attempt was made to provide the information in a form that was readily available and understandable to all potential user groups. Graphics were used whenever possible to clarify complex ideas and to reduce the size of the report.

This report is based on the best information and data currently available concerning distribution of fish and wildlife resources in the northern

Bering Sea-Norton Sound region, the impacts of oil and gas development on fish and wildlife resources, and the mitigative measures appropriate for reducing the biological impacts of oil and gas development. Although considerable effort was expended in order to produce the most comprehensive report possible, the scope of this report was limited by:

1. Time - The time allotted for this project was 15 ½ months.

2. Scale - The size of the study area required information to be depicted at a scale of 1:500,000 on reduced U.S.G.S. topographic maps.

3. Available Information - Decisions made in all phases of the project were based on an existing data base. The Alaska Department of Fish and Game, to the best of its knowledge and within the time allowed, has reviewed the available research data relating to the various phases of the project. A review of the literature and other available information reveals that many data gaps exist and that additional research is needed to provide a more adequate data base on which to make decisions. The Department recommends that site specific field research be conducted in areas designated for specific petroleum facility sites or activities.

Northern Bering Sea-Norton Sound Study Area

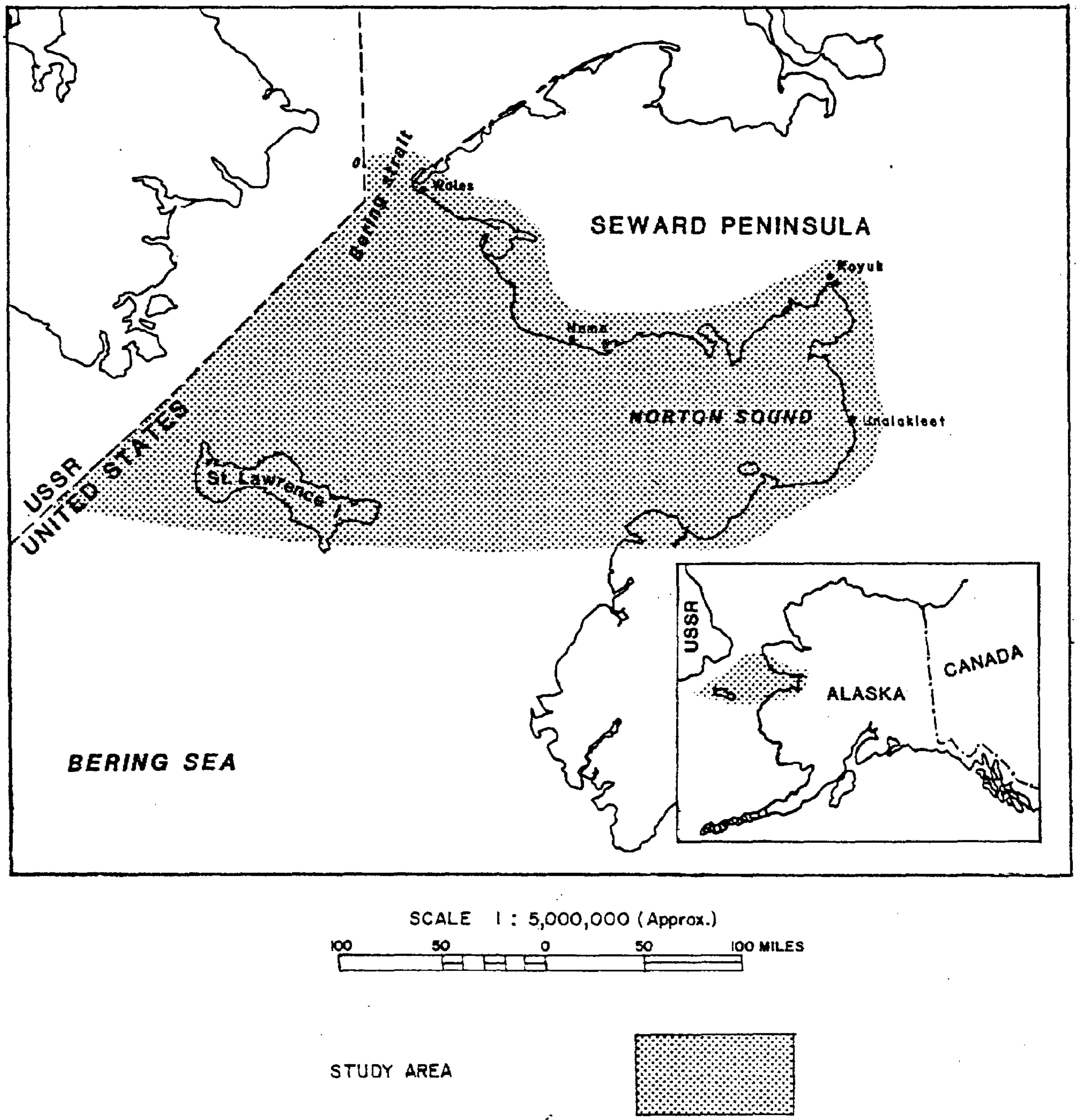


Figure 1

Location and General Description of the Study Area

Physical Description

The northern Bering Sea-Norton Sound region is situated in northwestern Alaska and includes those areas bordered on the east by longitude 160°W, in the west by longitude 174°W, in the north by latitude 66°N, and in the south by latitude 63°N. For the purposes of this study, terrestrial boundaries have been delineated to include all watersheds which drain into Norton Sound proper. The coast of Norton Sound from Cape Prince of Wales southward consists mainly of narrow beaches with the terrain rising steeply immediately behind (Selkregg, 1976). The shoreline is generally smooth with only a few prominent bays such as Port Clarence, Golovnin Bay, Norton Bay and Pastol Bay; and isolated headlands such as Capes Denbigh and Darby. Flat coastal lowlands may be found intermittently scattered throughout this region, occurring at such locations as south of Cape Denbigh, along the entire east coast of Norton Bay, the coastline from Cape Nome to Solomon, and the entire Yukon prodelta. Sand and gravel spits are common, and act as protective barriers for shallow lagoons which lie adjacent to the coastline. Several isolated islands ring the perimeter of Norton Sound; these include Sledge Island, Besboro Island, Egg Island, and Stuart Island. Major drainage basins in Norton Sound include the Kuzitrin, Niukluk, Koyuk and Unalakleet rivers. The Yukon River which lies at the southwestern edge of Norton Sound is the single most influential source of sediment and freshwater in this region.

Norton Sound is enclosed to the north and northeast by the Seward Peninsula, and to the south and southeast by the Yukon-Kuskokwim Coastal Lowlands. The extensive uplands of the Seward Peninsula consist of broad, convex hills and flat divides that are 152 to 610 meters (500 to 2,000 feet) high. These uplands are indented by sharp, V-shaped valleys, isolated groups of rugged, glaciated mountains 52 to 96 kilometers (20 to 60 miles) long 16 kilometers (10 miles) wide with summits 762 to 1,433 meters (2,500 to 4,700 feet) high, and coastal lowlands and interior basins.

Major mountain ranges on the Seward Peninsula include the Kigluaik, Bendeleben, and Darby mountains. Lakes fill several large, shallow volcanic craters in the northern part of the peninsula and several depressions between lava flows in the central upland. There are no glaciers on the Peninsula, and it is underlain by continuous to discontinous permafrost (Selkregg, 1976).

Along the southern and eastern portions of Norton Sound lies the Yukon-Kuskokwim Coastal Lowland Section. This is a marshy plain with low hills of basalt in the vicinity of St. Michael, while the lowland area around Shaktoolik is a lake-dotted coastal plain with an isolated range, the Denbigh Hills, at its western end (Selkregg, 1976). Most of the Yukon Delta is comprised of coastal tundra, with land and water roughly evenly divided. There are no trees over most of the Delta. Willows and alders are the only large woody plants, which become more scarce, and virtually disappear toward the coast, giving way to diminutive alpine willows, sedges and other tundra vegetation (Gusey, 1979).

The marine area of the northern Bering Sea-Norton Sound region is characterized by the Bering - Chukchi Platform, a smooth submarine plain 30 to 150 meters (100 to 500 feet) deep, dissected by old stream valleys cut during the Pleistocene era when the sea level was lower. Several islands, St. Lawrence, Big and Little Diomede, King, Sledge, and the Punuk Islands rise abruptly from the plain. Most of the islands are rolling uplands up to 305 meters (1,000 feet) high bordered by steep, rocky, wave-cut cliffs. St. Lawrence Island, the largest, is about 161 kilometers (100 miles) long and 32 kilometers (20 miles) wide. It is chiefly a lake-dotted bedrock plain of ancient volcanic origin less than 30.5 meters (100 feet) high. Isolated mountain groups, bordered by old sea cliffs, rise to altitudes of 305 to 457 meters (1,000 to 1,500 feet) (Selkregg, 1976).

Shallow water conditions characterize most of the study area. The deepest portion, in the northwest corner, is just over 49 meters (160 feet) and a channel 46 meters (150 feet) deep lies just off the eastern edge of St. Lawrence Island (Hanley et al., 1980). A deltaic fan created by the Yukon River forms a large shoal generally less than 15 meters (50 feet) deep in the southwest portion of Norton Sound. The Sound itself has an average depth of 18 meters (60 feet) (Cacchione and Drake, 1978), and is relatively uniform except for an anomolous channel located just offshore from the city of Nome (Hanley et al., 1980).

Climate

The northern Bering Sea-Norton Sound region is an area of extreme seasonal variability (Muench, 1980). The climate is mostly trasitional except for the extreme eastern corner of Norton Sound, which is continental, and some coastal areas which are maritime (Selkregg, 1976).

Winter usually extends from November through May, during which time temperatures average from -15 to -12°C (5 to 10°F). Marine ice formation typically commences in November in shallow bays and lagoons along the northern shore of Norton Sound, with first ice occurring in Norton Bay. By mid to late December the entire study area including the northern Bering Sea is essentially covered with broken first-year ice or, in nearshore regions, stable shorefast ice. Winds prevail from the north and northeast during winter months, providing the mechanism by which large amounts of ice are transported to southern portions of the Bering Sea. Wind velocities exceeding 112 k.p.h. (70 m.p.h.) have been recorded during all months from October through March (USCP, 1979). Annual snowfall may range from 127 to 178 centimeters (50 to 70 inches) a year.

Summer generally persists from June through early September. Storms moving through this region during these months can cause extended periods of cloudiness and rain. The nearly continuous cloud cover during July and August results in an average of 45 cloudy, 12 partly cloudy, and only 5 clear days for the 2-month period (USCP, 1979). Precipitation ranges from 38 to 51 centimeters (15 to 20) inches a year.

During late summer and fall, storms are frequent and usually arise from the southwest. Whenever a particularly intense storm crosses or approaches a coastline, some portion of the shore will experience an increase in sea level and another will experience a decrease. Storm surges, the term used to decribe such occurrences, are the difference between observed sea level and the sea level that normally would have occurred without a storm (Brower et al., 1977). In 1974, a storm surge in Norton Sound resulted in extensive damage to some coastal communities, including Nome and Unalakleet. Total rise of water was estimated at 7.6 meters (25 feet) where the normal tidal range is 1.2 meters (4 feet). Storms of this magnitude are thought to occur once every thirty years (Wise and Searby, 1977).

Biological Resources and Human Use

The northern Bering Sea-Norton Sound region is clearly of major importance for a variety of animal species, particularly marine mammals and birds. During the transition periods of spring and fall an immense number of marine mammals funnel through the relatively narrow confines of the Bering Strait, en route to summering areas in the Chukchi Sea and Arctic Ocean to the north, or wintering areas in the central and southern Bering Sea to the south. The exact size of these populations remains largely unknown, however it has been estimated that there are approximately 200,000 to 250,000 walrus, 200,000 to 250,000 spotted seals, 1,000,000 to 5,500,000 ringed seals, 300,000 bearded seals, 9,500 belukha whales, 1,700 to 2,900 bowhead whales and 16,500 to 19,000 gray whales present in western and northern Alaska waters. A large majority of these animals either migrate through, reproduce, overwinter, or feed in the Norton Basin annually.

Twenty-four seabird colonies scattered throughout this region support an estimated 4.3 million birds. The seabird populations on St. Lawrence and Little Diomede Island account for an estimated 2.7 and 1.2 million birds respectively. These aggregations are the largest and third largest in the Bering Sea. Large percentages of some seabird species nest wholly within the northern Bering Sea-Norton Sound region. For example, colonies located on St. Lawrence Island support 62% of the crested auklet population in the eastern Bering Sea; and least auklets breeding on St. Lawrence and Little Diomede Island encompass 79% of this species' eastern Bering Sea population.

Because of its geographic location, Norton Sound is heavily used by waterfowl, shorebirds, and passerines migrating between southern wintering grounds and northern breeding grounds in the Alaskan and Siberian arctic. The entire Yukon-Kuskokwim Delta stretching south from Norton Sound is recognized as one of the most productive waterfowl habitats in the world; it is estimated that there are 3 million waterfowl and over 100 million shorebirds present during summer months. More than half of the continental population of black brant nest in this area, as do 80% of the world's population of emperor geese.

The Yukon River Delta is also very important in terms of number of fish produced. The Delta is a major migratory route for two to five million spawning salmon each year, and is a principal rearing area for outmigrating juvenile salmon. In addition, the Delta provides important habitat for sheefish, ciscos, and other whitefish, all of which are major subsistence fishery items for local residents of this region.

The northern Bering Sea-Norton Sound region supports a rapidly developing commercial herring and king crab fishery, as well as a nearshore set net fishery for salmon. These fisheries harvest an average of 2,250,000 pounds of king crab, 1,173 metric tons of herring, and 900,000 salmon annually. Although these fisheries comprise only a small percentage of the total State harvest of these species, they are of significant importance to the local economy. Dollar value estimates for 1979 Norton Sound commercial fisheries products were $2,721,805 for king crab, $777,608 for herring and herring roe-on-kelp, $876,547 for salmon caught in Norton Sound proper, and $7,619,500 for all salmon harvested from the Yukon River system.

There are roughly 18,000 Native residents in this area; the majority of the inhabitants reside in more than 26 small villages scattered along the coast and the major river systems. Nearly all of these people rely on subsistence harvests of fish and game resources for a substantial portion of their livelihood. Because of the availability of a variety of animal species such as whales, walrus, seals, salmon, marine fish, shellfish, terrestrial mammals, seabirds and waterfowl, this region probably supports the largest and most diverse subsistence harvest in the State.

PHASES & ACTIVITIES OF
OIL & GAS DEVELOPMENT

PHASES AND ACTIVITIES OF OIL AND GAS DEVELOPMENT

Phases of Oil and Gas Development

The development of petroleum resources can be separated into five phases including 1) pre-exploration, 2) exploration, 3) development, 4) production and transportation, and 5) shutdown. In order to predict specific environmental impacts from oil and gas development, it is necessary to understand what kinds of activities are occurring within each of the five phases (see Table 1).

1. Pre-Exploration

The search for offshore oil and gas begins with an analysis of the geologic characteristics of an area. Geophysical surveys are used to identify and locate geological formations that may contain oil and/or gas. If such formations are found, Continental Offshore Stratigraphic Test (COST) wells are drilled to gather additional information. Unless extensive oil and gas resources are found, no permanent onshore facilities are needed to support this phase.

2. Exploration

During the exploration phase, exploratory wells are drilled to determine whether commercial quantities of oil and/or gas are present at a given site. If no commercial discovery is made the oil industry abandons the lease. If sufficient quantities of oil and gas are discovered, additional wells are drilled to determine the size and extent of the area. Production platforms are ordered and a method for transporting the crude oil is selected. Exploratory activities are supported by temporary service bases located onshore.

3. Development

The development phase is the period of greatest onshore and offshore activity. Onshore, a variety of facilities such as permanent service bases, terminals, pipelines, storage yards and port facilities are built to support the construction of offshore platforms and the production of oil and gas once they start flowing from the production platforms. Offshore, production platforms or gravel islands are installed and development wells are drilled. Submarine pipelines are laid to transport oil and gas from offshore platforms to onshore treatment facilities and storage terminals.

4. Production and Transportation

Production begins as soon as an offshore well is ready to produce, the transportation system is completed, and onshore facilities to store oil are constructed. All facilities built during the development phase become operational. Additional processing facilities such as refineries, petrochemical plants, and liquified natural gas plants may also be built. Gas pipelines are constructed during this phase.

5. Shutdown

When oil and gas reserves in an offshore production field are exhausted, most facilities will be shutdown, dismantled, or converted to another use. Offshore facilities such as production platforms will be dismantled. The United States Geological Survey normally requires that casings and pilings be cut 15 feet below the sea floor and removed. The well site area is dragged to remove any obstructions. Pipelines are usually left in place because of the cost involved to remove them. The connection between the pipeline and the production platform is capped and sealed. Onshore facilities are either closed or converted to another use.

TABLE 1

OFFSHORE AND ONSHORE ACTIVITIES ASSOCIATED WITH PHASES OF OIL AND GAS DEVELOPMENT

ACTIVITIES	DEVELOPMENT PHASES: PRE-EXPLORATION	EXPLORATION	DEVELOPMENT	PRODUCTION AND TRANSPORTATION	SHUTDOWN
GEOPHYSICAL SURVEYING	X	X			
EXPLORATORY DRILLING		X	X	X	
PRODUCTION DRILLING AND PLATFORM INSTALLATION			X	X	
PIPELINES			X	X	
SERVICE BASES		X	X	X	X
PLATFORM FABRICATION YARDS			X	X	
TREATMENT FACILITIES			X	X	
OIL TERMINALS (MARINE TERMINALS)			X	X	
OIL REFINERIES *			X	X	
PETROCHEMICAL PLANTS *				X	
LIQUIFIED NATURAL GAS PLANTS				X	

* At this time, it is unlikely that these facilities will be built in the northern Bering Sea-Norton Sound Region.

Activities Associated with Oil and Gas Development

Oil and gas development involves both offshore and onshore activities which may potentially disturb and may adversely impact fish and wildlife resources in the coastal environment (see Table 2). Offshore development includes 1) geophysical surveying, 2) exploratory drilling, 3) production drilling and platform installation and 4) laying submarine pipelines. Onshore development mainly involves the construction of 1) service bases, 2) platform fabrication yards, 3) treatment facilities, 4) oil or marine terminals, 5) oil refineries, 6) petrochemical plants, and 7) liquified natural gas plants. The following is a description of each of the activities which may result in potential damage to fish, wildlife and aquatic plants of the coastal region.

1. Geophysical Surveying

The initial step in searching for petroleum deposits is to analyze the geologic characteristics of a potential development region. Seismic and other types of geophysical surveys are used to identify and locate geological formations such as reservoirs or statigraphic traps that may contain oil and/or gas. This data is used by the oil industry to determine which submerged lands appear potentially promising for the development and production of petroleum. Continental Offshore Stratigraphic Test (COST) wells are often drilled as a result of these preliminary surveys. Core samples taken from these wells identify rock layers and their structure, and the composition of rock material that may be present, which helps to confirm the possibility of petroleum accumulations in that area.

2. Exploratory Drilling

Exploratory drilling is the major activity associated with the exploration phase of offshore petroleum development. Exploratory wells are drilled based on data obtained from geophysical surveying. If commercial quantities of oil or gas are discovered, additional wells will be drilled to determine the size of the field and the quantity of hydrocarbons present. Temporary service bases are needed to support offshore exploratory operations.

3. Production Drilling and Platform Installation

If oil is discovered in commercial quantities, platforms are installed or artificial islands are constructed from which production wells are drilled. The number and placement of production wells depends on the extent of the field, rock porosity, viscosity of the oil, field pressures, and other factors. Thirty or more wells may be drilled from a typical platform or island. These production platforms are stationary and remain in place for the life of the field (20 to 30 years).

4. Submarine Pipelines

Pipelines transport oil and natural gas from offshore production platforms to onshore processing, storage and loading facilities except when such products are stored on the platform and transferred directly to tankers for shipment. Offshore loading of oil directly

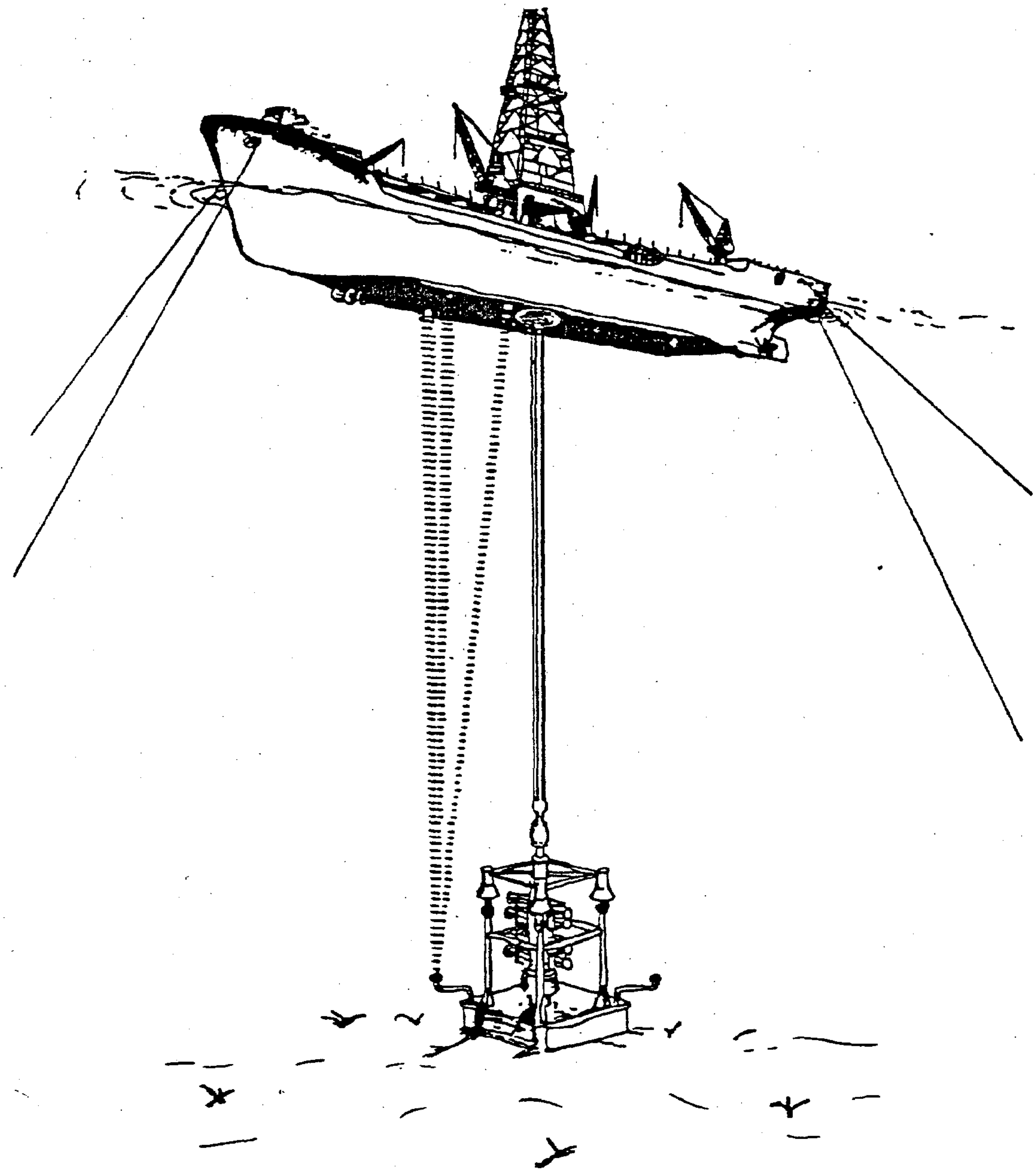


Figure 2. Drillship used in exploratory drilling.

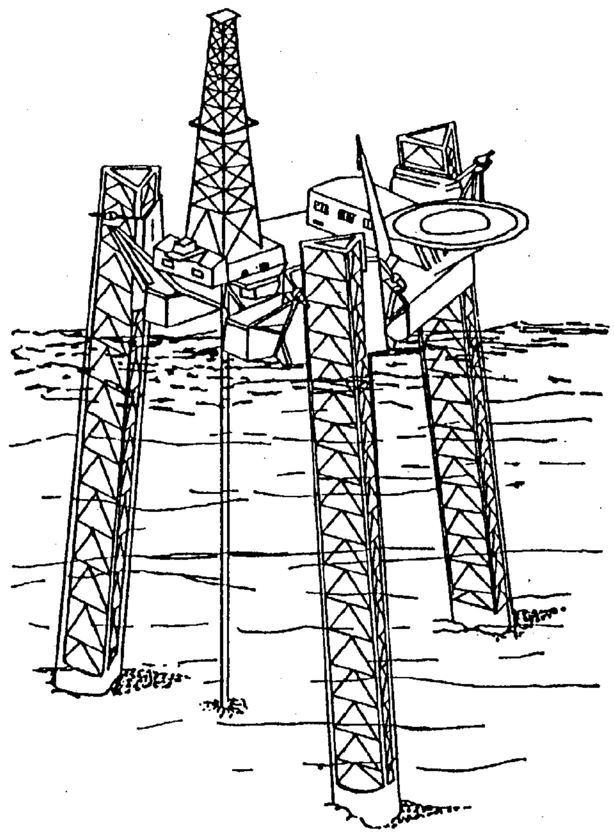


Figure 3. Jack-up drilling rig.

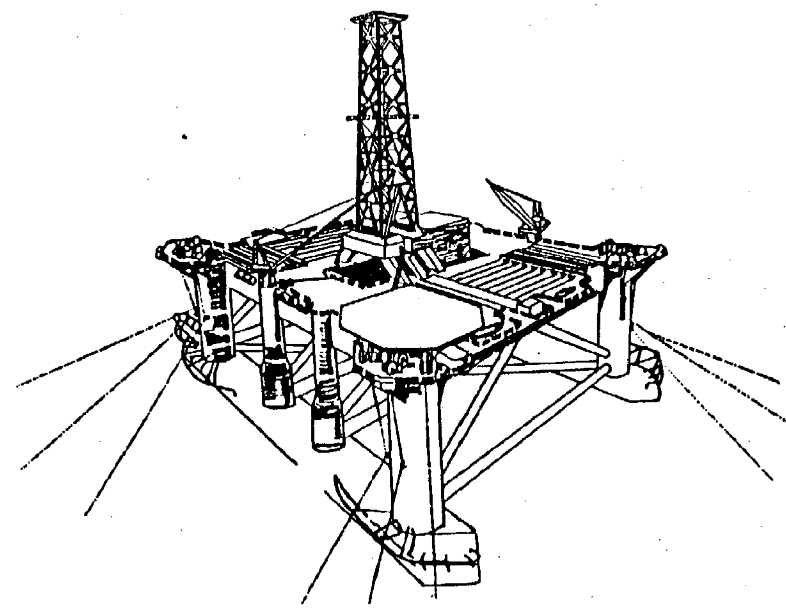


Figure 4. Semi-submersible drilling rig.

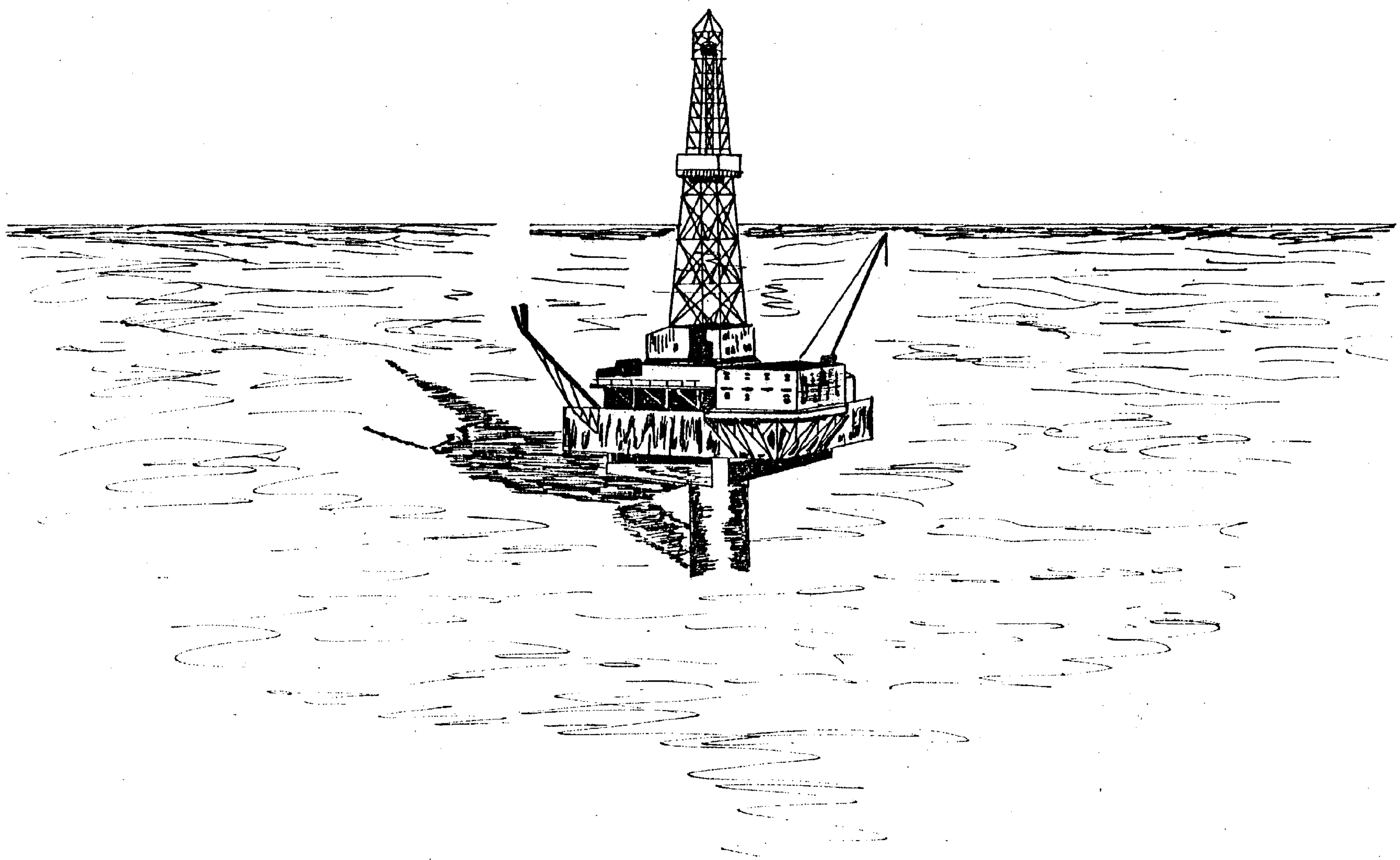


Figure 5. Mono-pod drilling rig

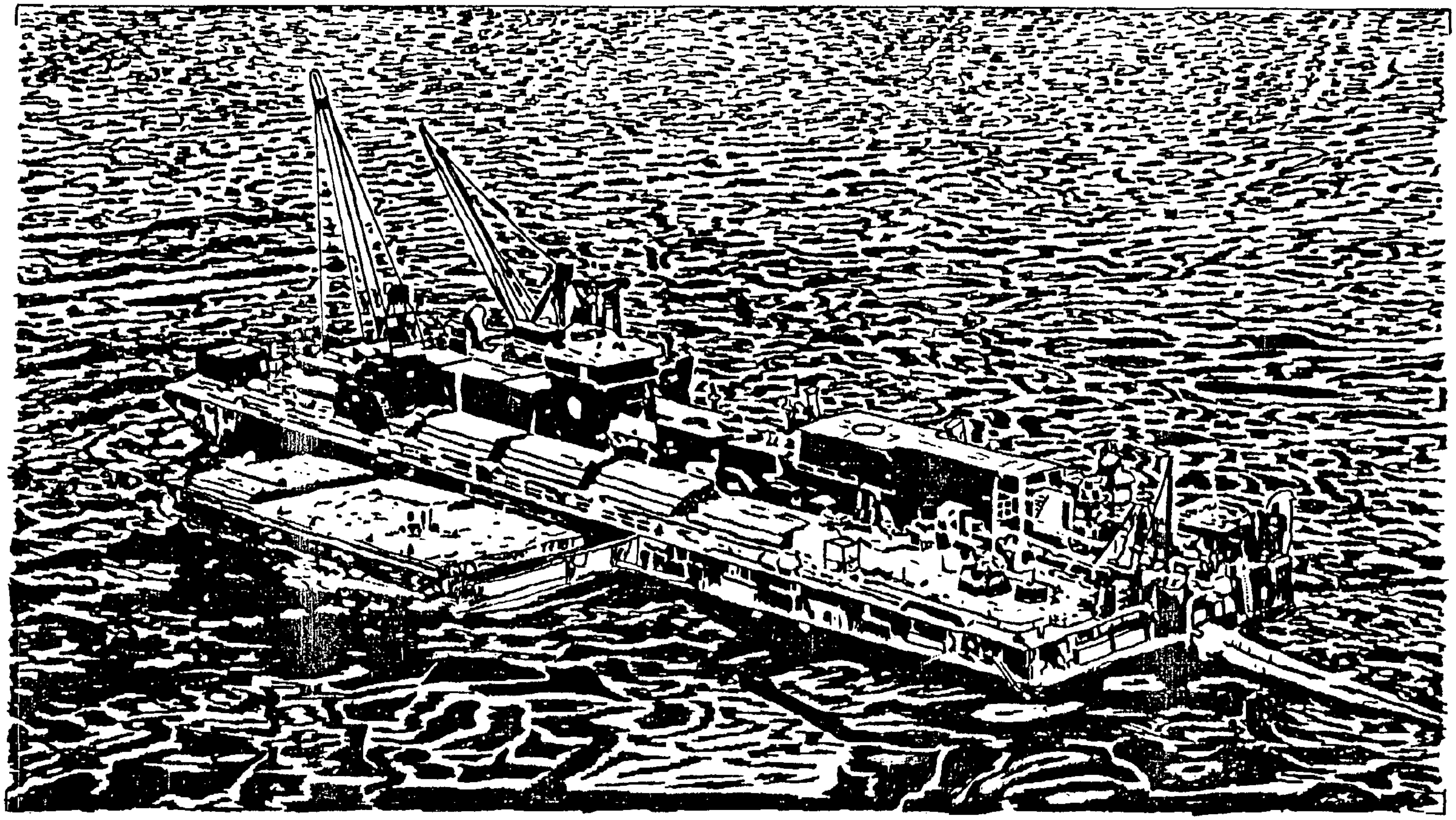


Figure 6. Pipeline laying barge. Pipelines are constructed onboard and laid simultaneously.

into tankers is generally used in fields of limited production. Natural gas is almost always transported to shore by pipeline. Between the offshore field and the coast, pipelines are buried beneath the ocean floor or are laid directly on the bottom. As they come ashore (landfall) they are buried underground and proceed toward onshore treatment and storage facilities.

5. Service Bases

Onshore service bases provide the necessary services and supplies for offshore petroleum operations. They are usually the first onshore facilities constructed. Crew members and materials required to operate the rigs and offshore platforms are transported from service bases to offshore operations by supply boats, crew boats, or helicopters.

Temporary service bases established during the exploratory phase of petroleum development are used to transfer materials (e.g., pipes, drilling muds, fuel, food, solid wastes, and crew members) between land and the offshore drilling rigs. Supply boats, crew boats, and helicopters operate out of these bases; therefore, they must provide harbor services for berthing and supplying boats, dock space for loading and unloading supplies, warehouse and open storage space, a helipad, and quarters for supervisory and communications personnel. Existing facilities are used if available, otherwise new structures must be built.

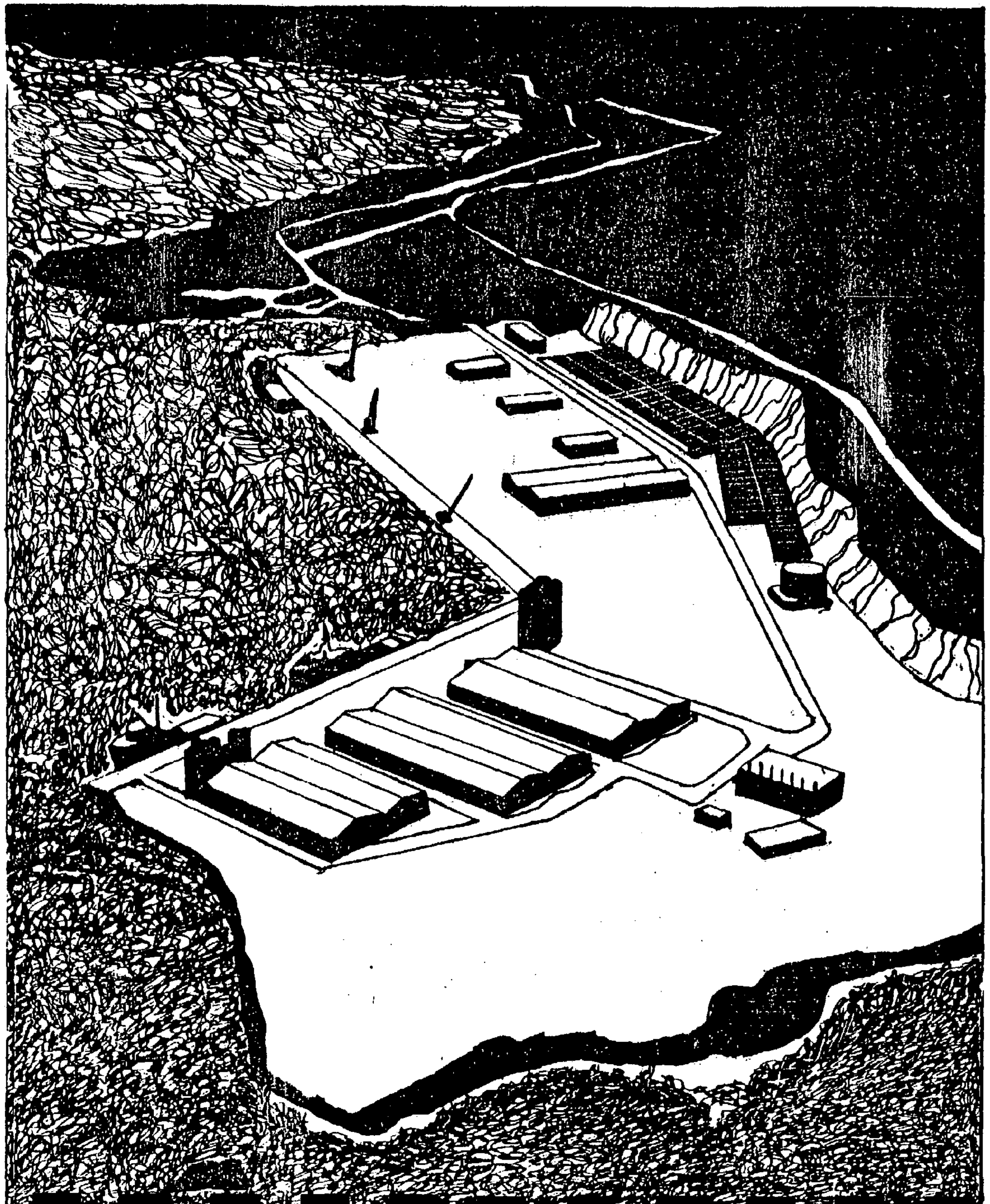


Figure 7.
Service bases are typically the first onshore facilities constructed.

If commerical quantities of oil and gas are found in the exploratory phase, temporary service bases are expanded to accommodate the increased offshore and onshore activities generated during the development and production phases. Permanent service bases provide the same services and support as temporary service bases only on an expanded scale.

6. Platform Fabrication Yards

The platforms used to drill for and produce offshore oil and gas are built in platform fabrication yards. Two major types of platforms are used, steel or concrete. Large waterfront sites with deep drydock basins are needed for the construction of concrete platforms; however no facilities of this type currently exist in Alaska. Steel platforms would have to be constructed outside Alaska and transported to the drilling site. Drilling rigs of the type used onshore or on artificial islands have been constructed in Alaska.

7. Treatment Facilities

Treatment facilities separate natural gas and formation water from crude oil. These facilities can be located offshore on the production platform or onshore as a separate facility, in combination with a marine terminal (facilities associated with waterborne shipments of crude oil), or a gas processing plant. Generally, the process of separating the oil from water begins offshore and is completed onshore.

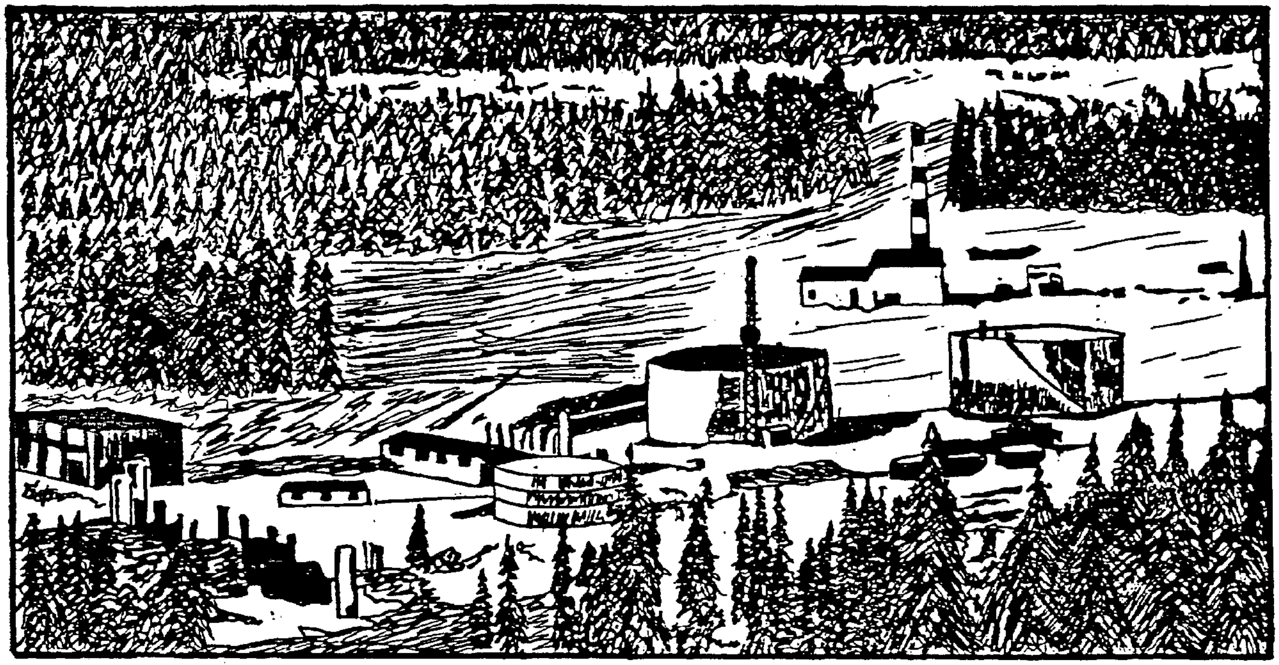


Figure 8. The Trading Bay treatment plant on the west side of Cook Inlet.

8. Oil Terminals (Marine Terminals)

Oil terminals are used to store crude oil from offshore production platforms and then load it aboard tankers for delivery to refineries and outside markets. Oil terminals may be located either onshore or offshore, although onshore oil terminals are more commonly chosen. Submarine pipelines deliver the oil to the onshore terminal site. If the oil has already been separated from its impurities, it goes directly into storage tanks. If not, the oil undergoes separation treatment at an onshore treatment facility. The processed oil is then stored in tanks for eventual shipment by tankers. Onshore oil terminals are generally located along the waterfront although the storage facilities could be built inland.

9. Oil Refineries

Refineries convert crude oil into various petroleum products including gasoline, fuel oil, kerosene, asphalt, and propane. Crude oil is brought to the refinery by pipeline and/or tanker and is temporarily stored in tanks. In Alaska the oil is then distilled, refined, and blended into a few final products which are stored for later shipment. Refineries do not need to be located along the coast, but if they are, a pipeline would be needed to connect the refinery to a sheltered harbor where both crude oil and refined products would be transported by ship to market areas. Refineries are highly visible components of the entire production of petroleum and may elicit public controversy regarding their location.

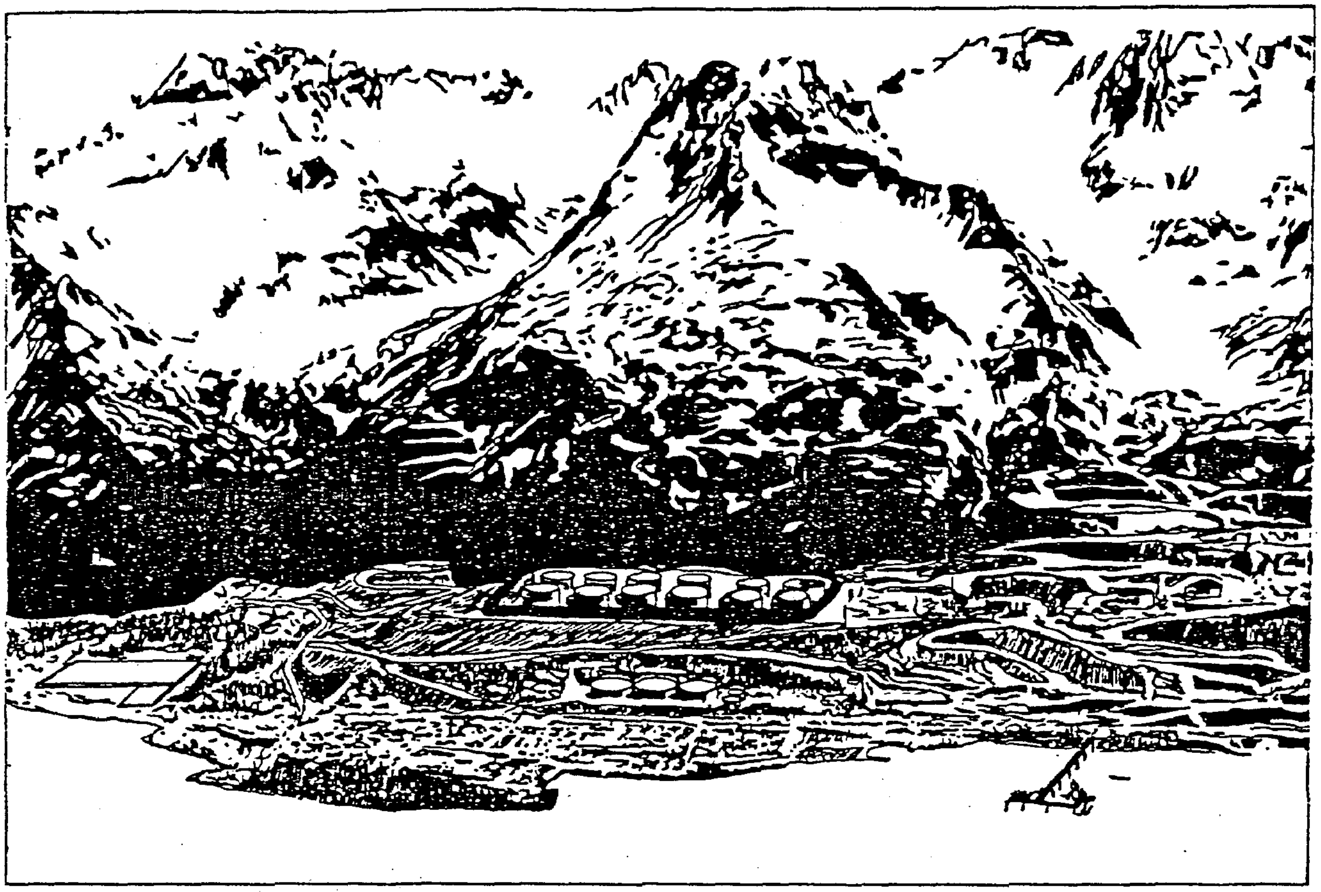


Figure 9. The Valdez Terminal in Valdez, Alaska serves as a storage and distribution center for oil transported from Prudhoe Bay via the Trans-Alaska Pipeline.

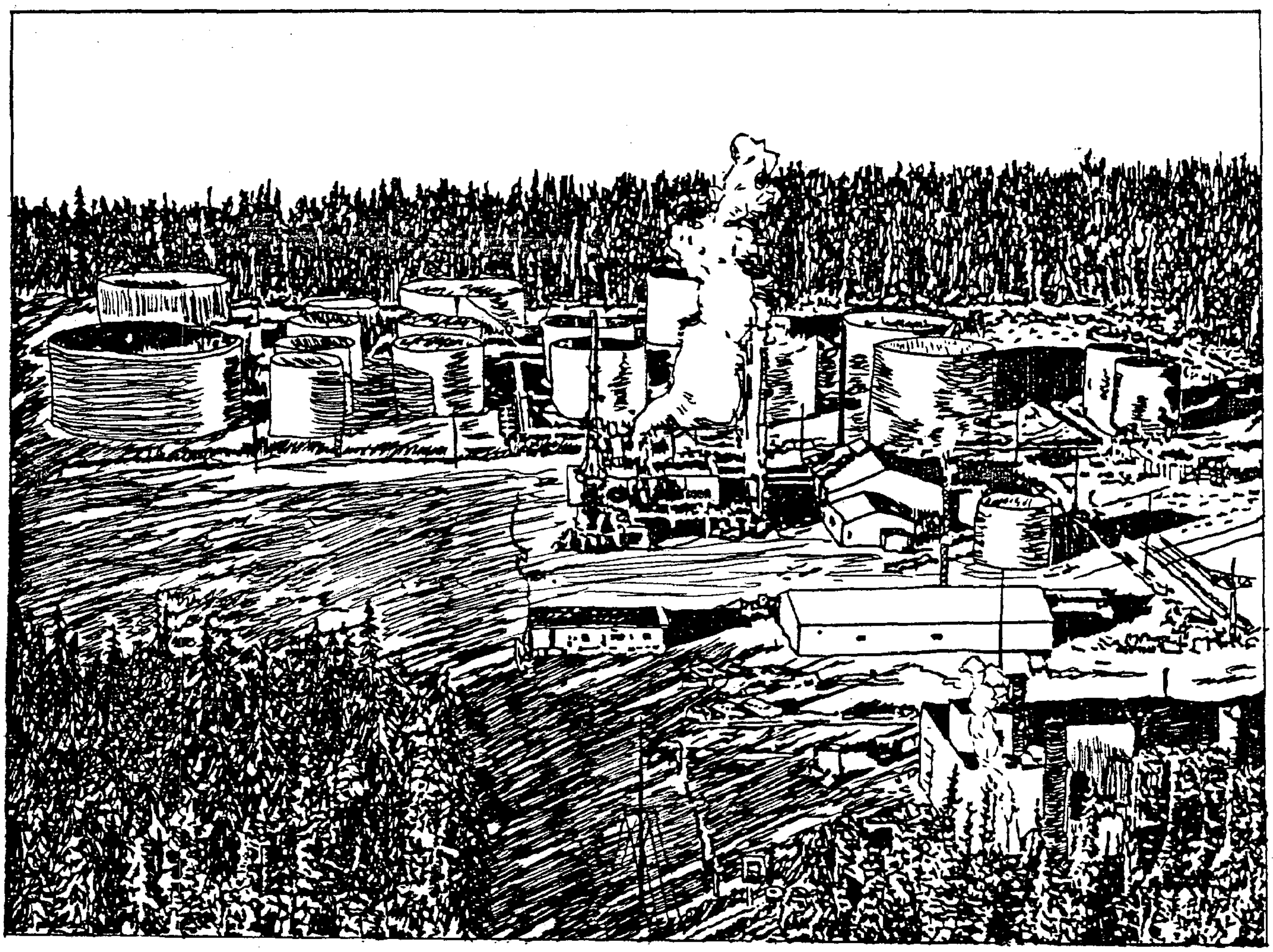


Figure 10. Chevron refinery near Kenai, Alaska.

10. Petrochemical Plants

To produce petrochemicals which are final products themselves (toluene, benzene, ethylene) or which may be used to make other products, petrochemical plants use feedstocks derived from various oil refinery products and from natural gas liquids. In Alaska petrochemical plants are not usually an essential part of the development of petroleum. It is usually more economical to ship crude oil and liquid natural gas in bulk to market areas than to transport a number of petrochemical products. If petrochemical plants are built in Alaska they will be located onshore near refineries or marketing areas.

11. Liquified Natural Gas Plants

Liquified natural gas (LNG) plants receive natural gas via pipelines from offshore gas fields, cool and compress it, and transfer it to cryogenic tankers for transport to regasification plants located near the market. Liquifying natural gas and transporting it by tanker is a convenient way to move gas over distances too great for pipelines. The only LNG plant in the United States is located at Nikiski, near Kenai, Alaska. This plant produces LNG which is transported to Japan by cryogenic tankers. LNG plants are usually located on large tracts of land away from populated areas because LNG spills create a serious hazard from fire and explosion. LNG plants are often built along the waterfront where marine facilities and sources of cooling water are available.

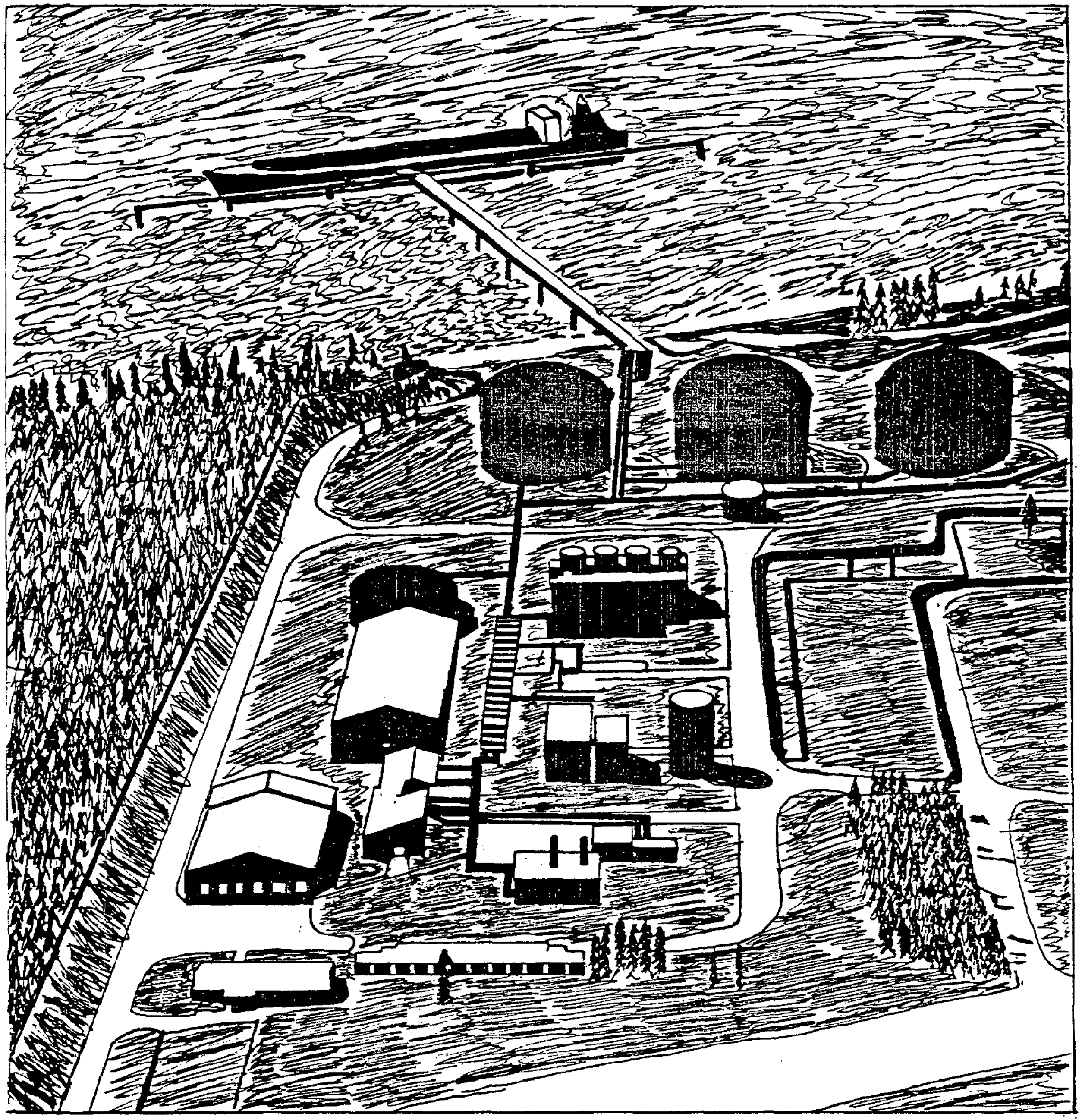
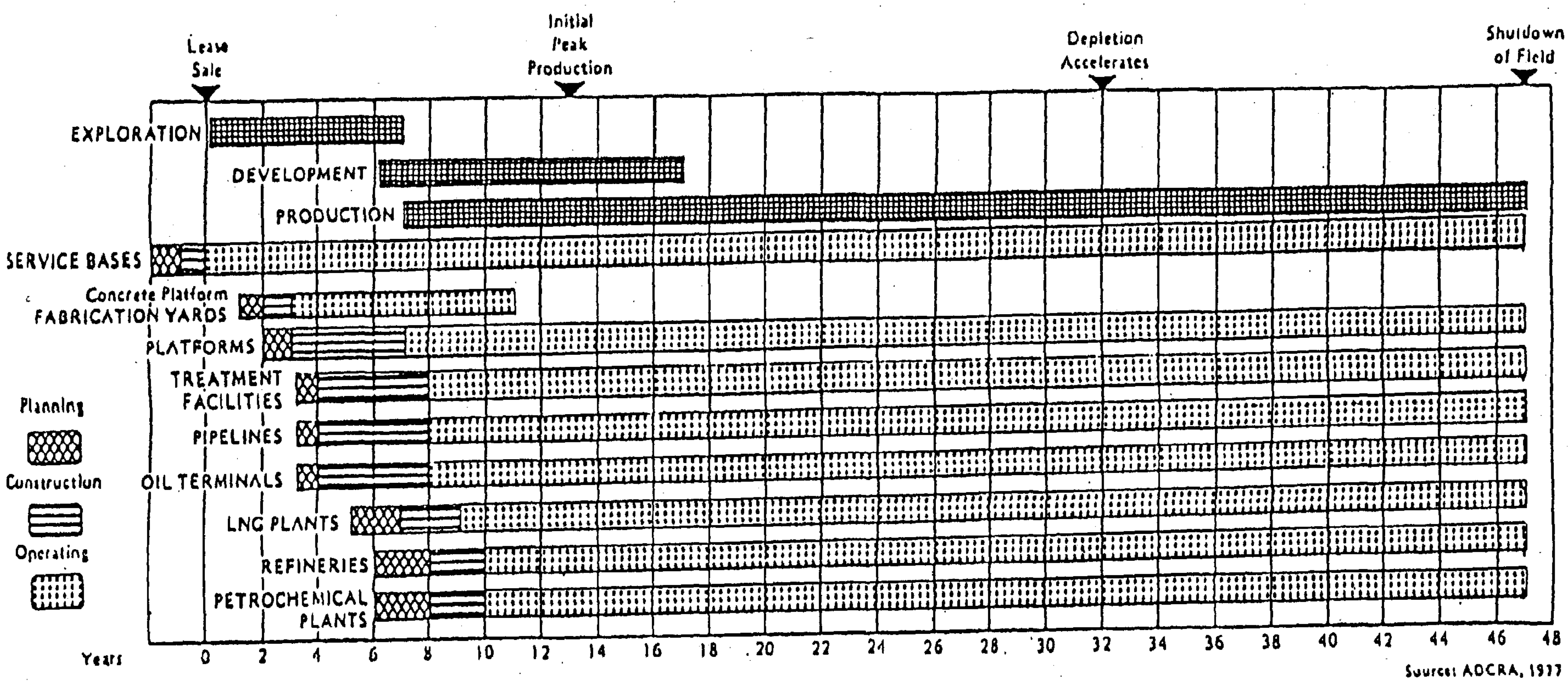


Figure 11. Liquified Natural Gas (LNG) plant at Nikiski, near Kenai, Alaska.

Figure 12
Timing of Facilities and Activities
in an OCS Lease Area



Source: ADCRA, 1977

TABLE 2

DISTURBANCES CAUSED BY ACTIVITIES ASSOCIATED WITH OIL AND GAS DEVELOPMENT

DISTURBANCES \ ACTIVITIES	GEOPHYSICAL SURVEYING	EXPLORATORY DRILLING	PRODUCTION DRILLING AND PLATFORM INSTALLATION	PIPELINES	SERVICE BASES	PLATFORM FABRICATION YARDS	TREATMENT FACILITIES	OIL TERMINALS (MARINE TERMINALS)	OIL REFINERIES *	PETROCHEMICAL PLANTS*	LIQUIFIED NATURAL GAS PLANTS
SITE PREPARATION	X	X	X	X	X	X	X	X	X	X	X
NOISE AND DISTURBANCE	X	X	X	X	X	X	X	X	X	X	X
DRILLING MUDS AND CUTTINGS		X	X								
OIL POLLUTION		X	X	X	X	X	X	X	X	X	
DREDGING AND FILLING, GRAVEL MINING, AND GRAVEL ISLANDS		X	X	X	X	X	X	X	X	X	X
SHORELINE ALTERATION			X	X	X	X	X	X	X	X	X
FORMATION WATERS			X				X		X	X	
COOLING WATERS AND WATER WITHDRAWAL		X	X		X	X	X	X	X	X	X
INTERFERENCE WITH SUBSISTENCE, COMMERCIAL AND SPORT HARVEST	X	X	X	X	X	X	X	X	X	X	X
AIR POLLUTION					X	X	X	X	X	X	X
SECONDARY DEVELOPMENT			X		X	X	X	X	X	X	X

* At this time, it is unlikely that these facilities will be built in the northern Bering Sea–Norton Sound Region.

IMPACTS & MITIGATIONS

IMPACTS AND RECOMMENDED MITIGATION MEASURES

Introduction

This section addresses the following disturbances caused by oil and gas development: site preparation, noise and disturbance, drilling muds and cuttings; oil pollution; dredging and filling, gravel mining, and gravel island construction; shoreline alteration; formation waters; cooling waters and water withdrawal; interference with subsistence, commercial, or sport harvests; secondary development; and air pollution.

The discussion of each disturbance is divided into two parts: 1) Sources and Biological Effects; and 2) Sensitivity of Areas and Recommended Mitigative Measures.

1. Sources and Biological Effects - The information presented in this section was obtained during the course of an extensive literature review concerning the sources of oil and gas related disturbances and the effects that these disturbances have on fish, wildlife, and aquatic plants. It was found that a considerable amount of information is available on the impacts of oil pollution; however, additional research is needed for the other onshore and offshore impacts of oil and gas development. Impact tables have been included in order to provide a brief summary and quick means of reference for the various types of disturbances identified, the species affected, the types of studies conducted, the researchers or authors involved, and

the effects observed. Impact tables have not been provided for site preparation, air pollution, secondary development or harvest interference due to the generalized nature of these disturbances.

2. Sensitivity of Areas and Recommended Mitigative Measures - the biological sensitivity of various areas in the northern Bering Sea-Norton Sound region was determined after synthesizing both the information on biological resource concentrations, and the impacts of disturbances on fish, wildlife, and aquatic plant species. Sensitivity designations were made using the available information. In many cases, the data available were insufficient to determine either the extent of a biological resource or the effects of a disturbance within reasonable statistical limits. As new information becomes available area designations for resources may be altered, however, it is felt that the important habitats have been identified.

Areas were ranked as having a low, moderate, or high sensitivity to the impacts of a particular oil and gas disturbance based on their value as productive fish and wildlife habitat. In order to insure the maintenance of existing populations of fish, wildlife, and aquatic plant resources in the northern Bering Sea-Norton Sound region, some areas should be excluded from specific types of oil and gas development. Highly productive or unique areas that should remain unchanged in order to maintain existing fish and wildlife populations were included in high sensitivity areas. Moderate sensitivity areas were those areas which supported valuable fish and wildlife resources but where environmental impacts from oil and gas development could be prevented or reduced if development took place according to specific environmental guidelines. Areas were designated as having a low sensitivity if the existing data base did not indicate the presence of significant populations of fish and wildlife (such as near existing townsites), or where existing regulations are adequate to protect biological resources.

It is also possible that future studies may reveal portions of designated low sensitivity areas to be more important than currently thought, although large charges are not anticipated. Mitigating measures are provided in order to minimize the adverse impacts of disturbances from oil and gas development on fish, wildlife, and aquatic plants in the northern Bering Sea-Norton Sound region.

A

SITE PREPARATION

SITE PREPARATION

Sources and Biological Effects

During oil and gas development, the preparation of sites for the construction of facilities, roads, utility right-of-ways, and pipeline corridors can adversely impact the fish and wildlife of Norton Sound and the northern Bering Sea by altering or destroying their habitats. In addition to destroying habitat, site preparation can lead to other environmental problems such as alteration of natural drainage systems, sedimentation, permafrost degradation, and pollution of water from stormwater runoff and erosion.

Because existing facilities (construction docks, tanker terminals, and onshore support bases) do not exist in the Norton Sound-northern Bering Sea region, new facilities will have to be constructed. Extensive site alteration involving clearing, grading, filling, and gravel pad construction will be required prior to construction of these facilities, or for access roads, pipelines, and utility corridors.

As a result of site preparation processes, habitats of local fish and wildlife populations are often altered or destroyed. Species of wildlife that are sensitive to disturbance will abandon the area (Longley et al., 1978). If site preparation only alters a small part of a species habitat and if the surrounding area is not at peak carrying capacity, the displaced species may successfully relocate nearby. However, if the disturbed area is large in relation to the total available habitat, or if a species has specific habitat requirements and the area altered provided the only suitable habitat, the species may be eliminated from the area. It is also possible that site preparation could create new habitat which will be colonized by different species from the surrounding area (NERBC, 1976). Impacts of site preparation will be most severe in Norton Sound and the northern Bering Sea if habitats which are important to fish and wildlife production are destroyed. Critical habitats in Norton Sound and the northern Bering Sea include: streams and rivers which provide habitat for fish spawning, rearing, and overwintering; wetlands which are vital components of the ecosystem and provide valuable habitat for fish, waterfowl, shorebirds, moose, and brown bear; *Fucus* beds which are important habitat for herring spawning; and rocky islands and seacliffs which are valuable to nesting seabird colonies.

Other adverse environmental effects, besides habitat destruction, may result from the preparation of onshore facility sites. As areas are cleared for construction, natural ground vegetation is removed and soils are exposed to the erosional processes of wind and water. During storms, runoff containing eroded soils is carried into coastal streams and marine waters, degrading water quality and interfering with normal biological processes. When sediments are added to the water it becomes cloudy, blocking light penetration and inhibiting the growth of algae and other aquatic plants. These aquatic organisms are vital components of the ecosystem and supply the basic nourishment for the entire chain of life. Suspended sediments affect juvenile fish by causing inflamation of gill membranes, and can clog the feeding mechanism of filter feeding animals such as clams, mussels, and sponges. In addition to sediments, runoff from construction sites often contains contaminants, including metals from welding, riveting and paint spills; oil and chemicals; bacteria; and other undesirable matter, all of which may pollute coastal waters. Freshwater storm runoff flowing into nearshore waters changes the salinity and increases the stress on coastal marine resources (Shanks, 1978).

Another impact caused by site preparation is the alteration of the water and drainage systems by filling in or draining of coastal wetlands (bogs and marshes), by degrading the underlying permafrost, and by diverting or destroying natural drainage channels and watercourses. Altered drainage patterns can lead to vegetative changes that may in turn change the composition of fish and wildlife species using the area (NPRA Task Force, 1978).

In arctic and subarctic regions, permafrost degradation is a major concern during site preparation. When insulating vegetation and peat cover are removed or compressed by construction equipment, additional thawing of the active layer (that portion of the permafrost that thaws in the summer and freezes during the winter) can occur. This may lead to long term slope instability, permanent modification of surface drainage patterns, erosion, lasting scars on the tundra mat, and vegetation changes. However, insulation of permafrost by the use of gravel pads for roadways and work or building pads can also affect drainage patterns and cause deterioration of nearby permafrost areas. Permafrost can grow upward or aggrade under thick pads blocking drainage. Impoundment of water on the upslope side of pads can degrade underlying permafrost. Attempts to relieve the problem by placing culverts through the pad, can channelize the flow and induce thermal erosion downstream of the pad (USGS, 1979).

The severity of the impacts from site preparation will depend on the type and size of the facility being constructed, the time of the year construction is scheduled, the geology (soils, slope) and hydrology (rainfall, aquifer) of the construction area, the construction methods used, and the composition of plant and animal species in the construction area. Many of the most adverse impacts of site preparation can be minimized through careful siting and design of facilities.

Sensitivity of Areas and Recommended Mitigative Measures

Areas in the northern Bering Sea and Norton Sound were ranked as having low, moderate, or high sensitivity to the impacts of site preparation (see Map A). These designations were based on available data and were made after evaluating the following criteria:

1. The sensitivity of each fish and wildlife species or habitat to site preparation.

2. The degree of sensitivity to site preparation which is experienced by each species during the various stages of its life history.

3. The time of year that these critical life history stages occur and the period during which each species would be most affected by site preparation.

4. The location of habitats where critical life history stages occur.

5. The productivity of the habitat.

6. The uniqueness of the habitat.

7. The species population numbers and relative importance of the population.

8. The degree to which the impacts of site preparation could be mitigated.

Specific considerations and assumptions that were made in the ranking of various habitats included:

1. The assumption that site preparation activities would occur on land or in nearshore areas. Impacts in streams or nearshore areas would only occur as a result of runoff from the site or from extension of an onshore site into adjacent waters (filling). Impacts arising in marine waters from dredging, filling, or the construction of gravel islands are discussed in the Dredging and Filling, Gravel Mining, and Gravel Islands section.

2. Impacts of site preparation would be greatest in eelgrass beds, wetlands, tideflats and lagoons. These habitats are generally highly productive areas that would be altered or destroyed by site preparation.

3. Fucus and kelp beds, highly productive habitats than can be altered or destroyed by site preparation, were ranked as moderate because of their widespread nature. It was felt impacts could be mitigated by limiting the size of projects, or by providing buffer zones along the coast to prevent sediment laden runoff from entering the beds.

4. Species most sensitive to site preparation are those for which a critical life stage occurs in a sensitive habitat (i.e. waterfowl nesting and staging in wetlands) or in a restricted area (marine mammal haulouts, seabird colonies, and muskox winter concentrations).

5. Moderate sensitivity designations were applied to those areas where it was felt that the adverse impacts of site preparation could be mitigated or prevented by careful siting, design, and by the use of buffer zones between the construction sites and nearby streams or coastal waters. Areas included in this category were: salmon streams and nearshore rearing areas, herring and capelin spawning areas, raptor nesting areas, and moose wintering areas. Actual fish spawning sites and raptor nest sites would be highly sensitive.

6. Important fish and wildlife habitats where species are relatively wide spread, such as marine mammal migration routes, muskox summer range, and areas of demersal fish abundance, were considered to have low sensitivity to the impacts of site preparation.

7. Impacts to harvest areas would arise primarily from noise and disturbance during construction and from the physical loss of harvest areas. These impacts are addressed on the Noise and Disturbance, and Interference with Subsistence, Commercial and Sport Harvest maps.

Sensitivity Designations and Mitigative Measures

LOW SENSITIVITY AREAS

The designation of low sensitivity was given to areas where impacts of site preparation would be less adverse than in moderate or high sensitivity areas. Activities relating to site preparation in low sensitivity areas should be conducted according to existing environmental regulations such as Federal noise level standards, EPA (Environmental Protection Agency) air and water quality standards, local zoning ordinances, and Coastal Zone Management guidelines.

MODERATE SENSITIVITY AREAS

The designation of moderate sensitivity was given to those areas where impacts of site preparation on fish and wildlife could be prevented, minimized or ameliorated. Habitats included in areas of moderate sensitivity are:

1. *Fucus* or kelp beds.
2. Salmon streams and nearshore rearing areas.
3. Herring spawning, possible spawning and overwintering areas.
4. Capelin spawning and possible spawning areas.
5. Waterfowl molting areas.
6. Raptor nesting areas.
7. Moose wintering and calving areas.

Site preparation activities in areas ranked as moderately sensitive should be conducted according to existing environmental regulations and the following guidelines:

General Mitigations

1. Vital fish and wildlife habitats should be avoided as sites for oil and gas facilities (see Map A).

2. Before site preparation begins the environmental, geologic and hydrologic aspects of the construction site should be studied. Facilities should be sited where the impacts of the facility on the environment and the environment on the facility are minimized.

3. Site preparation activities should be scheduled at times when the impacts on critical fish and wildlife life processes such as nesting or pupping will be minimal (see Table 3).

4. Development plans should include procedures for controlling erosion, runoff, and sedimentation, for preserving natural water drainage systems, and for protecting permafrost.

5. Wetlands, tideflats, and wet tundra areas should not be drained, filled, or polluted.

6. The destruction of native vegetation cover should be avoided.

7. Size of facilities should be minimized, and facilities should be consolidated where possible.

8. Dust should be controlled at construction sites. Dust accumulation around roads and construction sites can cause early snow melt and vegetation changes. These changes can lead to changes in drainage patterns. Dust should be controlled by watering, not oiling. Runoff from oiled surfaces can pollute local waters and the hard surface created by oiling lengthens deterioration time following project abandonment.

Non-permafrost soils - erosion, runoff and sedimentation.

1. Clear only the minimum area needed for construction of facilities. Other parts of the site should not be disturbed. Any remaining vegetation will reduce erosion and runoff in adjacent areas.

2. Finish grades so that the flow of water is directed along natural drainage courses and through natural terrain.

3. Vegetative buffers should be left along all shorelines, sloughs, bays, rivers, streams, and other surface waters in order to trap sedimentation and pollutants and to control stormwater flow. The width of the buffer should be determined by slope of land, severity of erosion, and vegetation type.

4. Cleared areas should be revegetated as rapidly as possible after site preparation activities in order to stabilize exposed soils.

5. Where possible natural vegetation should be used to revegetate cleared areas. It is adapted to local climatic conditions and it reduces the loss of wildlife habitat because birds and mammals are adapted to it. Nurseries should be established to provide arctic adapted species for revegetation.

6. On a site that has been cleared but on which construction will be delayed, temporary vegetation (i.e., rapidly growing grains and grasses) may be planted on exposed soils to prevent erosion. Newly seeded areas can be protected until vegetation becomes established by laying down netting, preferably jute or other biodegradable material.

7. Stormwater runoff may be diverted away from exposed soils by cutting parallel troughs across slopes to intercept the downward flow of surface waters. On steep slopes, bench terraces can be constructed to achieve the same purpose. Both of these methods are used to divert stormwaters into sediment basins or into vegetated buffer strips so that sediments can be removed.

8. Sediment basins or detention ponds may need to be constructed in order to detain runoff and trap sediment thus decreasing the siltation and contamination of coastal waters.

9. Vegetated waterways (swales) should be used to carry stormwaters away from construction sites instead of concrete storm drains.

10. Erosion in waterways (e.g., channels, ditches) may be reduced by planting grasses along their courses. The establishment of grasses is an effective way of removing sediments from the water.

11. Structures sited on slopes of unstable materials should be built on fill or supported on piles.

12. Riprap material used to stabilize river banks and prevent erosion should be of sufficient size so that it cannot be carried into the stream by normal or flood currents.

Non-permafrost soils - preserving natural water drainage systems.

1. Areas that have high water tables should not be drained. Excavation in these areas should be limited to such structures as ponds, artificial lakes, or other containment projects which preserve the natural water system. These artificial basins should be designed to function as natural systems, which means they should be fairly shallow and have gentle slopes. Improperly designed basins may become polluted within a few years. Vegetative buffer strips should surround the basins for restoration of runoff water quality.

2. Areas that are regularly flooded should not be drained or altered. Elevating structures on piles will cause the least disturbance to the flood plain.

3. There should be no excavation, filling, land clearing, grading, channelization, or removal of natural vegetation, and no discharge of pollutants into wetlands or wet tundra areas.

4. Upland sites should be selected for facilities unless they are water-dependent. If facilities are water-dependent, then the non-water dependent parts of the facility (e.g., parking areas) should be located outside of the wetland area.

5. Excavation in wetlands should be avoided except for essential public purposes (i.e. electrical lines, pipelines, and water lines that cannot feasibly be rerouted). Excavation should be limited to as small an area as possible.

6. Solid-fill roads or other structures which obstruct the natural flow of water should not be built in wetlands. The excavation of fill for these structures causes additional adverse impacts. If the construction of roads or other types of access through wetlands is unavoidable, they should be placed on pilings rather than on fill.

7. If drilling for oil and gas is unavoidable in wetlands, ecological disturbance can be reduced by using directional drilling to drill several wells from one site.

8. Wetlands that are altered during the construction of facilities should be restored to their natural state after the project is completed.

    a. The original soil should be saved and replaced after project completion.

    b. The area should be restored to its original topographic configuration.

    c. The area should be revegetated with native species.

9. When the movement of heavy construction equipment through wetlands or wet tundra is unavoidable, culverts and bridges should be used to minimize degradation of the natural drainage patterns. Winter movements are desirable because the substrate is frozen, fish and wildlife are generally absent, and damage is minimized.

10. Construction areas should be graded so that the flow of surface waters is along natural drainage courses.

11. Site preparation activities in wetlands and wet tundra should be scheduled during winter when the least biological damage will occur.

12. Tributary streams should not be altered.

13. The use of permeable surfacing materials such as gravel, rocks, and shells, over groundwater recharge areas is more desirable than the use of impenetrable surfacing such as asphalt. Impenetrable surfaces such as paved parking lots and roads prevent groundwater recharge and accelerate storm runoff. Water that normally filters through the soil remains on the surface. Increased runoff from paved areas results in pollution, causes erosion, and increases flooding.

14. Stormwater should be retained by constructing detention ponds which collect runoff and then slowly release filtered and purified water to the coastal system.

Protection of permafrost

1. Site specific studies should be conducted to define the type of permafrost terrain present and the degree of potential instability that must be considered in site design.

2. Construction on well-drained, coarse sediments presents fewer problems than construction on poorly-drained, fine-grained sediments.

3. Construction in permafrost areas should use the latest available technology to prevent drainage alterations, channelization of flows, ponding, and permafrost degragation.

4. Where gravel pads are required, impact on drainage patterns can be reduced by building circular pads or orienting one corner of square pads upslope.

5. Gravel pads should be of sufficient depth to insulate the underlying permafrost.

6. Artificial material, such as styrofoam insulation, can used in conjunction with gravel to provide insulation to the permafrost layer and to reduce gravel needs. However, the long term impacts of artificial materials have not been adequately tested.

7. Temporary structures should be built on piles. Gravel pads should only be used where weight or stability requires their use. Use of piles reduces permanent environmental damage and reduces commitment of surface area for temporary structures.

8. Refrigerated piles can be used in marginal permafrost to assure the permanently frozen state of sediments around the piles. Piles should be spaced far enough apart to allow thawing between them or drainage patterns will be altered.

9. To minimize environmental damage, construction of facilities should be minimized. Unnecessary duplication of roads such as construction of roads between facilities where access to the facilities from main roads has already been provided, and the

use of pipeline construction pads where existing roads could be used, are examples of activities that should be avoided.

10. Facilities should be consolidated so that the area of disturbance is reduced.

11. Vehicular travel and movement of construction equipment should be restricted to adequately constructed roads. Off-road travel should only be allowed after the tundra surface is sufficiently frozen and snow depths are adequate to prevent surface damage.

12. Where possible, off-road travel should be restricted to low-surface-pressure vehicles. Impacts of off-road travel by tracked or tractor-type vehicles can be lessened by:

    a. Traveling only where and when there is sufficient snow cover to protect the vegetative surface and avoiding steep slopes and snow-free areas.

    B. Using the same route each year when activities extend over several winters. Use of the same route for more than two years, providing that the peat layer continues to insulate against summer thaw, is less damaging than a series of parallel roads across the terrain.

In order to implement these guidelines, site specific studies will have to be conducted on a case by case basis. In instances where information is not available regarding the effects of site preparation on the various stages of animal life history, more research will have to be done to determine these impacts.

HIGH SENSITIVITY AREAS

The designation of high sensitivity was given to habitats where the impacts of site preparation would be extremely adverse to fish and wildlife resources. Habitats in this category include:

1. Eelgrass beds, wetlands and tideflats (both highly productive/heavily used and those where productivity is not known), and lagoons.
2. Seabird colonies and peregrine falcon nesting/use areas.
3. Waterfowl nesting and staging areas including major and important staging areas, emperor geese molting and staging areas, snow geese staging areas, swan nesting/use areas, and sandhill crane use areas.
4. Waterfowl and shorebird spring concentration areas.
5. Shorebird fall staging areas and important habitat.
6. Marine mammal haulouts including walrus recurrent and occasional haulouts, spotted seal and sea lion haulouts.
7. Grizzly bear denning areas and possible polar bear denning areas.
8. Muskox wintering and calving area.

Because the destruction of habitat caused by site preparation is usually permanent, facilities should not be sited in areas of high sensitivity.

TABLE 3: MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND SPECIES, HABITATS OR HARVEST ACTIVITIES ARE MOST SENSITIVE TO SITE PREPARATION.

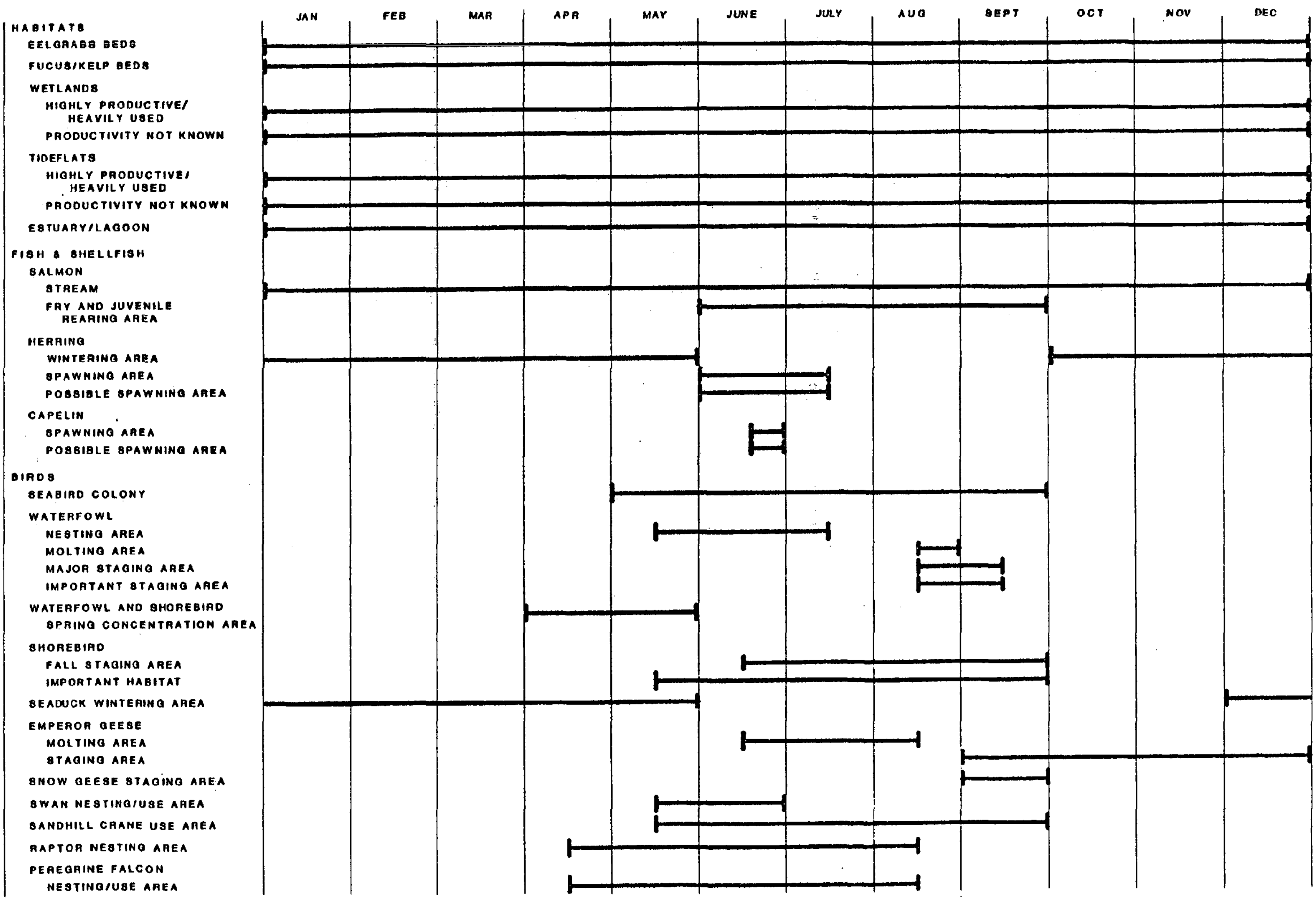
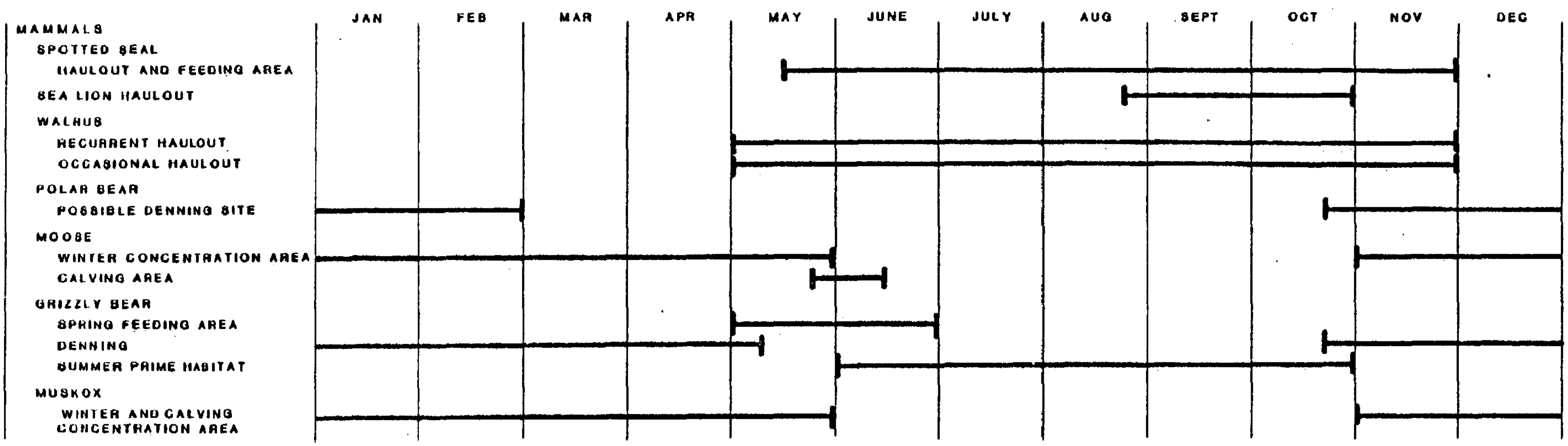


TABLE 3: (CONT.) MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND SPECIES, HABITATS OR HARVEST ACTIVITIES ARE MOST SENSITIVE TO SITE PREPARATION.



B

NOISE & DISTURBANCE

NOISE AND DISTURBANCE

Sources and Biological Effects

The intense level of support activity associated with offshore oil and gas exploration and development will cause various degrees of disturbance to fish and wildlife in the coastal environment. Noise and physical disturbance are primarily caused by an increase in helicopter, fixed-winged aircraft, and boat traffic; by heavy machinery used during site preparation, gravel mining, and construction of onshore facilities; by seismic exploration; and by an increase in human presence.

Projections for offshore oil and gas development in Norton Sound indicate that up to six wells could be drilled per year during exploration with approximately one month of geophysical (seismic) work per well. Each drilling rig would be supported by one helicopter and two supply boats (Hanley et al., 1980). No estimates are available for the number of trips required to transfer employees, parts, and supplies between offshore drilling vessels and shore. Additional increases in activity are expected during oil field development.

When birds or mammals are disturbed by noise or human presence they may either abandon or discontinue using favored breeding, feeding, nesting, staging or molting areas (Nettleship, undated; Geist, 1975). The impacts from noise and disturbance can be especially severe if they occur during critical periods in the life cycle of birds and mammals. These critical periods include such activities as breeding, nesting, pupping, and hatching. As a result of disturbance during critical periods, reproductive success may be reduced, resulting in lower populations (Nisbet, 1977).

Some wildlife species or individuals are able to adapt to predictable man-made sounds. McCourt et al. (1974) found caribou tracks within 0.4 kilometers (one-quarter mile) of an active base camp and airstrip during the spring migration period. In an another area however, caribou reacted to the simulated sound of an air compressor by altering their direction of travel and detouring around the simulator (McCourt et al., 1974). Lapland longspur breeding was unaffected in the vicinity of a gas compressor noise simulator (Gollop et al., 1974a).

Loud or unpredictable sounds, such as noises from rapidly approaching boats and aircraft, gunshots, or explosions are usually disturbing to nesting birds, and can result in direct mortality to eggs or young. Sudden noises alarm nesting seabirds causing them to move about and knock eggs or young off cliffs or out of nests thereby exposing them to predators such as gulls (Nisbet, 1977). Gyrfalcons place their feet under or between their offspring and when startled and not allowed time to respond unhurridly to intrusions, the parent birds may catapult eggs or young from the nest (Fyfe and Olendorff, 1976). Barry and Spencer (1976) studying the effects of oil well drilling on wildlife in the McKenzie River delta, found that of all the activities associated with drilling operations, low-flying helicopters caused the greatest disturbance to birds inhabiting the area within 2.5 kilometers (1.5 miles) of the drilling rig. Behavior patterns were altered and mortality increased due to the loss of eggs by predation. When adults were frightened away from the nests, gulls and jaegers would often take the eggs (NPRA Task Force, 1978). Egg mortality can also occur when eggs become overheated or chilled during the parent bird's absence.

The inability of birds to accomodate disturbance from humans, airplanes, and boats can result in the abandonment of nesting habitat and major losses of bird eggs and young (McKnight and Knoder, undated). Close overflights by fixed-wing aircraft near gyrfalcon nests early in their nesting cycle before egg laying begins, appears to cause nest desertions (Fyfe and Olendorff, 1976). Disturbance studies with breeding black brant, Pacific eiders, glaucous gulls, and Arctic terns at Nunaluk Spit and Phillips Bay, in the Yukon territory, in July 1972 indicated that human presence was the most critical form of disturbance affecting the incubating behavior of these species. Helicopter disturbance had the greatest impact on the incubating behavior of all species except Pacific eiders (LGL Limited, 1972).

Disturbance to birds is not limited to nesting activities. During the molt, birds are flightless and will concentrate in areas where they are protected from predators. Molting birds are under a considerable amount of physiological stress due to the large energy requirement necessary to grow new feathers. Studies have shown that aircraft traffic over sea duck molting areas will alter normal behavior patterns and therefore have a detrimental impact on sea duck populations by causing them to expend energy unnecessarily (McKnight and Knoder, undated). Studies by

LGL Limited (1972) indicated that sounds simulating those generated by compressors were disruptive to staging snow geese (McKnight and Knoder, undated). Salter and Davis (1974) reported that overflights of a Cessna 185 at altitudes of 91 meters (300 feet) to 3000 meters (10,000 feet) flushed all resting snow geese. The geese tended to flush at greatest distances when the aircraft was below 300 meters (1,000 feet) with flocks flushing up to 14.5 kilometers (9 miles) away from the aircraft. Non-nesting waterfowl populations were reduced on a small lake following float plane landings and taxiing (Schweinsburg et al., 1974).

Marine mammals are also detrimentally affected by noise and disturbance. Helicopters, low-flying aircraft, noisy boat traffic, and human presence are primary causes of pup mortality and the declining use of some areas by marine mammals (Trasky et al., 1977). In the Canadian Beaufort Sea, belukha whale movements were disrupted by gravel barge traffic during the construction of offshore islands. When a barge moved through a concentration of whales in a bay, whales up to 2.4 kilometers (1.5 miles) ahead of the barge reacted by moving rapidly away from the disturbance. Distribution of whales in the bay did not return to normal until 30 hours after the barge had passed. Heavily used barge routes appeared to impede, if not block, nearshore belukha movements. It was felt that the disturbance was caused not only by sound and movement of the barges but by the wake of suspended bubbles which remained in the water column for several hours after the barges had passed. The bubbles, which are suspended in the water column to a depth of a few meters, may be interpreted by the whales echo location signals as a barrier. A similar effect has been reported as occurring in the Pacific Ocean where wakes from tuna boats act as temporary barriers to movements of porpoises (Fraker, 1977).

Johnson (1976) in a study on the effects of human disturbance on a population of harbor seals on Tugidak Island, southeast of Kodiak Island, Alaska found that low flying aircraft resulted in direct mortality of harbor seal pups during the pupping season. Studies show that any loud or sudden noise can lead to a major disturbance which will frighten the seals into the water. During a disturbance pups may become permanently separated from their mothers and die of starvation. During the study aircraft flying below 400 feet, particularly those less than 100 feet, caused most, and sometimes all, of the seals to enter the water. Impacts from natural disturbances such as rockslides or an eagle landing in or near a group were usually confined to one locality and often affected only one, or just a few of the herds on the island; whereas, low flying aircraft circling the island caused the entire population to temporarily abandon haulout areas. As a consequence, low flying aircraft not only disrupted the seals daily activities, but resulted in a reduction of population through pup mortality. Most of the disturbance to harbor seals on Tugidak Island in 1976 was related to OCS exploration. Helicopters transporting geologists were the most severe disturbance factor (Johnson, 1976).

Seismic activities, used primarily during the exploratory phase of oil development, also cause disturbance to organisms in the coastal environment. Presently, non-explosive techniques such as side scan sonar, air guns and sparkers are used in marine areas to identify geological structures which may contain oil and gas reserves. Explosives and vibrating (vibroseis) equipment are commonly used on upland seismic surveys.

Non-explosive seismic techniques do not appear to physically injure fish. Falk and Lawrence (1973) have shown that air guns are non-injurious to fish populations in shallow waters. Although a certain amount of noise is emitted by non-explosive devices which can cause fish to move away from the pathway of a ship towing seismic equipment, it is not known how much actual disturbance is caused by this method of seismic exploration. Porpoises have been found to be attracted to side scan sonar, and other marine mammals such as belukha whales, which depend on sonar for communication, may also be similarly attracted (Holden, pers. comm., 1978). Fishermen have complained that fish flee during the use of these techniques.

Studies in Glacier Bay have shown that marine mammals, such as humpback whales, killer whales, and Dall porpoises are disturbed by boats. Ncise generated by boats can cause these animals to abandon an area where they are feeding, resting, or traveling. Observations in Glacier Bay revealed that within a 24 hour period, the number of humpback whales using an area decreased from sixteen to three as a result of boat-whale interactions. Boats causing the disturbance were either traveling through the area, trolling for fish, or were being used to observe the whales activities (Jurasz, pers. comm., 1978).

Gray whales are not overly disturbed by boats in open ocean situations, but vessel activity has excluded them from some lagoonal breeding areas in Mexico. Bowhead whales appear to be more affected by disturbance when restricted to narrow leads in the pack ice than when they are in the open ocean (Burns, pers. comm.).

Terrestrial mammals are affected by increases in aircraft activity and human presence. Individual animals and species react in varying degrees to the same disturbance. McCourt et al. (1974) found that moose, caribou, and grizzly bear all react to overflights by helicopters and fixed-wing aircraft. Caribou and moose reactions decreased as overflight altitudes increased. Aircraft above 182 meters (600 feet) elicited no response in moose, and aircraft altitudes of 305 meters (1,000 feet) or more elicited only occasional responses in caribou. Grizzly bear were more sensitive to disturbance than moose or caribou, but no correlations were found between altitude and sensitivity (McCourt et al., 1974). Sensitivities of terrestrial mammals to disturbance can vary according to the activity the animal is engaged in, season of year, and group size. McCourt et al. (1974) found that bedded caribou exhibited the strongest reaction to aircraft disturbance, with large groups responding more intensely than small groups. Sensitivity of the caribou to aircraft disturbance varied seasonally as well (McCourt and Horstman, 1974).

Non-explosive seismic operations can affect other species. Along the Beaufort Sea coast, Frost (1979) has found that ringed seal densities are reduced in areas of the shorefast ice zone where over ice seismic surveys and other activities have occurred. It is felt that the declines in seal density are caused by displacement rather than direct mortality. Animals will avoid or leave areas of seismic activity. Displacement of female ringed seals from the shorefast ice zone during pupping can lead to lower population levels. Newborn pups are helpless for six weeks after birth and will die unless attended by a female. Seals displaced to the moving pack ice are more susceptible to polar bear predation; and pups born on moving ice tend to be smaller, are weaned earlier, and may have reduced survival rates (Frost, 1979). Seismic work and human presence in areas of polar bear denning have apparently caused early den desertion (Lentfer, 1976, Belikov, 1976). Lentfer (1976) reported that a female polar bear with a new cub was observed out of a den a month earlier than normal in the vicinity of a seismic operation. The cub was extremely small and had trouble traveling. Early den desertions may affect cub survival.

Explosives are used during terrestrial seismic work and can disturb wildlife populations if detonated near bird nesting areas, or critical mammal habitats. Over pressures from seismic explosions can kill fish if detonated in or near fish producing lakes and streams.

During construction and operation of oil-related facilities, the population of Norton Sound and the northern Bering Sea region will increase (Hanley et al., 1980). The presence of more people in an area will lead to a certain degree of harassment to wildlife, either because species have not experienced disturbance before or because human activities may be similar to other alarm-producing stimuli (Geist, 1975). As a result of human populations increases, more people will participate in outdoor recreation including hunting, fishing, hiking, and boating. Machines used by people, such as off-road vehicles, snow machines, trail bikes and motors, will disturb wildlife. Disturbance and harassment are also caused by free roaming domestic pets (i.e., dogs and cats). Harassment, which by definition includes non-intentional disturbance of a repeated or prolonged nature, has both direct and indirect detrimental effects on individuals as well as groups of wildlife. Harassment elevates body metabolism and therefore affects an animal's body growth, development and reproduction. Secondary effects from physical exertion and temporary confusion induced by harassment can lead to death, illness or reduced fecundity. Animals will generally avoid or abandon areas where they have experienced harassment. Avoidance of harassment may lead to a reduction in the population's range, and ultimately a reduction of the population itself.

Activities which attract wildlife, such as improper garbage disposal or feeding animals, will lead to human-animal conflicts and could cause severe impacts on local wildlife populations if several animals must be destroyed. Bears are often attracted to these situations and are killed because they become a nuisance or threat to human life and property (NPRA Task Force, 1978). Other species attracted by garbage include fox, wolves, and wolverines. Improper garbage disposal also attracts gulls (including kittiwakes) and ravens leading to local increases in the populations of these predatory species. Displacement of more desirable seabird species by rapidly increasing gull populations has proven to be a serious problem in Europe, the eastern United States, Australia, and New Zealand (Drury et al., 1978).

Table 4 Effects of noise and disturbance on birds and mammals

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
TERRESTRIAL MAMMALS				
Caribou (Rangifer tarandus) Moose (Alces alces) Grizzly Bear (Ursus arctos)	McCourt et al., 1974	field observation	aircraft (Bell 206 helicopter, Cessna 185)	Caribou reacted more strongly to a Bell 206 helicopter than a Cessna 185 at low altitudes (300 ft). No difference in reactivity to different aircraft occurred for altitudes greater than 300 ft. The reactivity of caribou to aircraft disturbance decreased as the altitude of the aircraft increased, up to an altitude of approximately 1000 ft. Reactions to aircraft at altitudes greater than 1000 ft. were unpredictable but infrequent. Groups of caribou which were feeding or bedded reacted often to aircraft disturbance, the bedded animals exhibiting the strongest reaction. A correlation between group size and reactivity to aircraft was found at altitudes less than 300 ft. Larger groups reacted most often and most intensely. No outstanding changes in reactivity were observed between seasons. Moose reacted more often than not to aircraft at altitudes of less than 200 ft. Fixed wing aircraft at altitudes above 600 ft. elicited no reaction. Grizzly bear were more sensitive to aircraft disturbance than caribou or moose but no correlations between altitude and sensitivity were found.
Caribou (Rangifer tarandus)	McCourt et al., 1974	field observations	simulated air compressor (sound only - no movement or odor)	Reactions differed by season and activity of animals during spring migration. Direction of movement was altered by sound of the simulator. During the calving period, caribou within 1/8 mi. of operating simulator exhibited a significantly greater frequency of changes in activities than those around the non-operating simulator. During summer, animals moving within 30 yards deflected slightly away and exhibited alert postures. There was no evidence of reactions at greater than 300 yards. During fall migration evidence suggested that caribou were deterred from approaching closer than 1/2 mi. to the simulator.
Caribou (Rangifer tarandus)	McCourt et al., 1974	field observations	man made objects	Caribou tracks during spring migration were found within 1/4 mile of an active base camp and airstrip containing a number of trailers, other buildings, and numerous vehicles. Tracks and feeding craters were also found within 25 ft. of oil storage tanks at another location. A short detour (100-200 yards) was made around an unoccupied seismic camp by migrating caribou.
Caribou (Rangifer tarandus)	McCourt et al., 1974	field observation	presence of man	Activity of people on bank of river caribou were attemping to swim caused caribou to turn back at halfway point even though changing ice conditions greatly hampered return trip.
Caribou (Rangifer tarandus)	McCourt and Horstman, 1974	field observation	aircraft	Reactions of caribou to aircraft varied by season. The seasonal order of reactivity for flights below 300 feet (greatest to least) was found to be: post-calving, winter, spring migration, calving, fall migration, summer movement. However for flights at 300-600 feet a strictly chronological order of reactivity was observed (i.e. winter, spring migration, calving, post calving, summer). Reactions also depended upon terrain and group size.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Dall Sheep (Ovis dalli)	McCourt et al., 1974	field observation	simulated air compressor, helicoptor	During summer, male Dall sheep were adversely affected by simulated noise of a compressor and by helicopters. Disturbance resulted in behavorial changes and abandonment of range within 1 mi of simulator. Limit of sound disturbance, or duration of displacement were not determined.
Dall Sheep (Ovis dalli)	Reynolds, 1974	field observation	simulated compressor station sounds, aircraft	Sheep accustomed to aircraft noise at a mineral lick did not appear bothered by simulated compressor noise. However, sheep spent less time in the part of the lick with highest sound levels. Sheep showed strong reactions to low flying helicopters coming within 150 yards but mild to no reactions to aircraft as far away as 1/4-3/4 mi.
Dall Sheep (Ovis dalli)	Lenarz, 1974	field observation	helicopter	The majority of the sheep reacted to a helicopter flying by at a distance of 300-500 diagonal feet. Reactions ranged from casual movement away from the stimulus (49% of all sheep observed) to panic running (36% of all groups observed). The degree of reaction was found to be independent of the orientation of the helicopter to the sheep. Reaction was also independent of season and group size, however, ewes with or without lambs reacted stronger to disturbance than rams.
MARINE MAMMALS				
Polar bear (Ursus maritimus)	Belikov, 1976	field observation	human activity	Several bears deserted dens on Wrangel Island shortly after forming them because of presence of investigators. Other dens have been observed at close range without premature desertion.
Polar bear (Ursus maritimus)	Lentfer, 1976	field observation	seismic activity	A female polar bear with a new cub was observed out of a den a month earlier than normal near seismic operations. Cub was extremely small and had trouble traveling.
Gray whales (Eschrichtius robustus) Bowheads (Balaena mysticetus)	Burns pers. comm.	unknown	vessel activity	Gray whales are apparently not overly disturbed by boats in open ocean situations but vessel activity has excluded them from some traditional lagoonal breeding areas in Mexico. Bowheads are more affected by disturbance when restricted to open leads than when in open ocean.
Bowhead whales (Balaena mysticetus)	Fraker, 1979	unknown	boat traffic, aircraft	During studies in the Canadian Beaufort, bowhead whales were approached as close as 152 m (500 ft) before diving. No information was given for the maximum distance which caused the whales to dive. No adverse reactions were observed to whales from aircraft flying at altitudes of 300 m (1,000 ft) or more.
Humpback whales (Megaptera novaeangliae)	Jurasz pers. comm.	field observation	boat traffic	Within a 24-hour period the number of humpback whales using an area decreased from sixteen to three as a result of boat-whale interactions. Boats causing the disturbance were either traveling through the area, trolling for fish, or were observing the whales activities.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Belukha whale (*Delphinapterus leucas*)	Fraker, 1977	field observation	barge traffic	Aerial surveillance during barge movement through a concentration of whales in a bay showed that whales up to 1.5 miles from the barge reacted by moving rapidly away from the disturbance. Whale distribution in the bay did not return to near normal until 30 hours after the barge had passed. Heavily used barge routes appeared to impede and may have blocked whale movements in another area. It was felt that disturbance was not only caused by sound and movement of the barge but by the wake of suspended bubbles which remain in the water column for several hours. The bubbles which are suspended in the water to a depth of a few meters may be interpreted by the whales echo location signal as a barrier. This was reported as occurring in the Pacific Ocean where wakes from tuna boats act as a temporary barrier to movements of porpoises.
Belukha whales (*Delphinapterus leucas*)	Fraker, 1979	unknown	boat traffic dredging	In shallow waters, less than about 6 feet (1.8 m) deep, belukhas have reacted to boats and dredges at a distance of 1.5 to 2 miles (2.5 to 3 km) by moving away from them. Underwater sounds from dredging operations were calculated to have been perceptible to belukhas at ranges of 2.5 miles (4 km). In deeper water, however, they have been observed as close as 75 feet (25 m) from moving barge tows. A high frequency of marine traffic movements, about 25 per day, caused an apparent interruption of belukha whale movements. At a rate of about 15 traffic movements per day or less, belukha movements appeared unaffected. No adverse reaction to the presence of man-made islands was observed.
Belukha whale (*Delphinapterus leucas*)	Seaman and Burns (in press)	field observation and literature review	boat traffic	Local people in Kotzebue Sound have attributed a decline in the number of belukhas congregating in former hunting areas to increased fishing activity involving continuous traffic of many small outboard powered boats.
Belukha whale (*Delphinapterus leucas*)	Ford, 1977	unknown	gravel borrow operation	By relating sound attenuation rates and probable auditory sensitivity of belukha whales, it was calculated that whales could probably hear average sounds from two gravel borrow sites at a range of 2,900 meters. Certain transient sounds might be percieved at a range of 4,000 meters.
Belukha whale (*Delphinapterus leucas*)	Holden pers comm.	unknown	seismic surveys	Porpoises are attracted to side scan sonar and other marine mammals such as belukha whale which depend on sonar for communication may also be attracted.
Belukha whale (*Delphinapterus leucas*)	Fraker et al., 1978	field observation	aircraft	Belukha whales in shallow water in Cunningham Inlet, Canada, reacted strongly to an overflight by a twin otter flying at 1,000 ft. Bottom sediments were stirred up as the whales retreated to deeper water.
Belukha whale (*Delphinapterus leucas*)	Fraker, 1977	field observation	gravel islands	Although logistics traffic associated with island construction and operation has been observed to directly affect whales, the mere presence of an artificial island appears to have little effect. Substantial numbers of belukhas were seen, some within 100 m, near an operational island in the Canadian Beaufort.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Atlantic walrus (Odobenus rosmarus)	Salter, 1979	field observation	aircraft, boats	Walruses on land responded to 27% of 71 local flights by helicopters and to 35% of 31 flights by fixed-wing aircraft. No response to boat traffic was observed. Responses recognized were head-lifting, orientation toward the sea, and retreat into the sea. The level of response depended upon distance and altitude of disturbance approach. The only disturbances that caused reaction beyond head raising were those that occurred within 2.5 km. The maximum distance at which escape was precipitated was 1.3 km. A direct overflight by a single engine plane at 1500 m altitude over a herd of 46 caused head raising by up to 20 walruses and escape into the water by two. On another date, an overflight at 1000 m caused head raising by 31 to 41 walruses on land, orientation by 39, escape by 17.
Ringed seal (Phoca hispida)	Frost, 1979	aerial survey	seismic exploration	Densities of ringed seals were two to four times greater in areas where no seismic surveys had been conducted than in areas where surveys had been conducted. On the average there were only one-half as many seals in the areas of seismic operation. The decrease was attributed to displacement although mortality was not ruled out. Displacement from the shorefast ice zone during pupping is critical in that seals in the moving pack ice are more susceptible to polar bear predation and pups born on moving ice tend to be smaller, weaned earlier, and possibly have reduced survival.
Harbor seal (Phoca vitulina)	Johnson, 1976	field observation	aircraft	On Tugidak Island, Alaska, low flying aircraft resulted in direct mortality of harbor seal pups during the pupping season. Studies show that any loud or sudden noise can lead to a major disturbance which will send all seals into the water. During a disturbance pups may become permanently separated from their mothers and die of starvation. During the study aircraft flying below 400 feet, particularly less than 100 feet, caused most, and sometimes all, of the seals to enter the water. Impacts from natural disturbances such as rockslides or an eagle landing in or near a group were usually confined to one locality and often affected one or just a few of the herds on the island; whereas, low flying aircraft circling the island caused the entire population to temporarily abandon haulout areas. As a consequence, low flying aircraft not only disrupted the seals daily activities but resulted in reduction of population through pup mortality. Effects of low flying aircraft were greater on calm days than on "noisy" days during storms or strong winds and disturbance was greater from larger planes or helicopters than from the smaller planes. Most of the disturbance to harbor seals on Tugidak Island in 1976 was related to OCS exploration. Helicopters transporting geologist were the most severe disturbance factor.
BIRDS				
Nesting seabirds	Sowl and Bartonek, 1974	field observation and literature review	boats, human presence, aircraft	Seabirds nesting on cliffs are highly susceptible to disturbance. The incautious, close approach of aircraft, boats or people on foot almost invariably results in a panic flight of birds from cliffs. During incubation and brooding, each occurrence results in a rain of eggs or young from the cliff. Other chicks and eggs that are temporarily abandoned often fall prey to gulls, jaegers and other predators.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Peregrine falcon (Falco peregrinus) and other raptors	Fyfe and Olendorff, 1976	field observation	human presence	Factors causing nest desertion may vary within a species or between areas. The most critical time for many species is just prior to egg laying. Desertion of nest ledges has been observed (both before and during egg-laying) following single short visits to eyries of peregrine falcons. Peregrine falcons will usually "sit tight" during the several days just before and just after hatching and will allow people to approach closely. At such close quarters, however, the eventual hasty departure of the adult can crack eggs or injure young.
Gyrfalcons (Falco rusticolus) Peregrine falcons (Falco peregrinus)	Cade and White, 1976	literature review and field observations	human presence, aircraft	Peregrine falcons and gyrfalcons appear to be much more sensitive to disturbances on the ground than by close overflights of aircraft. During nesting surveys, close overflights by a variety of fix-winged aircraft and helicopters elicited no sudden flight or panic by nesting or incubating falcons although several cases of falcons aggressively attacking the aircraft were reported. Incubating females were especially reluctant to abandon nests. Long term effects of aircraft disturbance are not known although falcons continue to use cliffs close to busy Arctic airfields in Canada and Alaska. Ground disturbances such as geophysical survey parties, scientific investigative groups, use of chainsaws and other loud noises appeared to cause the most disturbance. Sensitivity is greatest during egg laying and incubation. Once eggs have hatched, adults can tolerate more activity around the nest.
Peregrine falcons (Falco peregrinus) Gyrfalcons (Falco rusticolus) and other raptors	Fyfe and Olendorff, 1976	field observation	aircraft	Authors suggest that helicopters, particularly turbo jets, have little effect on incubating falcons, eagles or ospreys, other than to provoke an occasional attack. Ospreys, gyrfalcons, and peregrine falcons can actually pose a hazard to helicopters because of this behavior. Fixed-winged aircraft flying at heights in excess of 450 meters (1,500 ft) above the nest site do not seem to present a disturbance. Data relative to nest occupancy following fixed-wing aircraft flying near nest sites at lower altitudes early in the nesting cycle before egg-laying suggest that such activities may cause nest desertions of gyrfalcons. To minimize disturbance at nesting cliffs approach to cliff should be as direct as possible. An approach from behind the cliff may result in the sudden appearance and sound of an aircraft directly over the nest site, which may make the attending adult fly in panic and fatally damage the eggs or young as it goes.
Snow geese (Chen caerulescens)	Salter and Davis, 1974	field observation	fixed-wing aircraft Cessna 185	Overflights by a Cessna 185 flushed all resting snow geese at altitudes of 300, 700, 1,000, 5,000, 7,000 and 10,000 ft. The geese tended to flush at greatest distances when the aircraft was under 1,000 ft with flocks flushing up to 9 miles away from the aircraft. All geese in an area 5 miles by 10 miles were driven from the area in 15 minutes by "hazing" with the aircraft.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Snow geese (Chen caerulescens)	Gollop and Davis, 1974	field observation	gas compressor, noise simulator, aircraft	Noise from a gas compressor simulator had a detrimental effect on use of a feeding area by snow geese. Only 1 flock out of 33 landed during operation of the simulator while between 1/3 and 1/2 of the flocks attracted to the area when the simulator was not present or not operating landed. When the simulator was first turned on, flocks within 3 miles left the area. Some returned to within 1 1/2 miles but were completely driven from the area and did not return following the landing of a float plane on a nearby lake.
Black brant (Branta bernicla) Common eider (Somateria mollissima) Glaucous gulls (Larus hyperboreus) Arctic terns (Sterna paradisaea)	Gollop et al., 1974c	field observation	Jet Ranger helicopter, Cessna 185 aircraft, fixed-wing and human disturbance	The combined disturbances of aircraft, helicopter and human presence caused a high % of altered incubation behavior and abandonment of nests resulting in low productivity especially for black brant and Arctic tern. Results indicated 1) Human presence was the most potent form of disturbance, affecting the normal incubating behavior of all species studied. 2) Aircraft disturbance affected the normal incubating behavior of black brant, glaucous gulls and arctic terns but had little obvious effect on common eider incubation. 3) Helicopters were more disturbing to birds than were fixed-wing aircraft. 4) Non-incubating birds showed greater intolerance to disturbance than did incubating birds.
Whistling swans (Olor columbianus) Canada geese . (Branta canadensis geese (Chen caerulescens)	Barry and Spencer, 1976	field observation	exploritory drilling rig	Studies at a new drilling rig in the Canadian Arctic showed that nest success was lower near the rig. Whistling swans had used the rig site the previous 3 years but the majority did not approach closer than 6.4 km of the rig although one nested 1 km from the rig. The closest approach by a family of Canada geese was 3.7 km. Large flocks came no closer than 8 km. Snow The closest snow geese approached was 4.2 km. Sandhill cranes fed within 800 m of the rig site. The major disturbance associated with the rig appeared to be helicopter traffic. During a drill steam test, birds 1 km from the rig appeared unaffected.
Whistling swans (Olor columbianus) Snow geese (Chen caerulescens) White-fronted geese (Anser albifrons) Widgeon (Mareca americana) Oldsquaw (Clangula hyemalis) Pintail (Anus acuta)	Barry and Spencer, 1976	field observation	helicopters, boats	Non-nesting snow geese and white-fronted geese flushed 3 km or more ahead of a supply helicopter and rarely returned. During the molt birds would run from approaching boats or low flying aircraft. Nesting snow geese would leave their nests and fly .8 to 2.4 km (1/2-1 1/2 mi) ahead of the helicopter when it was traveling at 150 km/hr (80 ks) at 90 m (300 ft). Birds began returning to nests when the helicopter was 80 m (1/2 mi) away. Resettling on nests took up to three-fourth of an hour because of territorial fights. Gulls and jaegers took advantage of unguarded nests during this time. A pintail duck nest 260-500 m (200-400 yds) from the drilling pad and under the flight path of supply helicopters, was robbed by jaegers and abandoned.
Sea ducks (primarily oldsquaw and surf scoters)	Gollop et al., 1974d	field observation	helicopter	No detectable numbers of sea ducks were driven from a molting area as a result of repeated helicopter disturbance. However, behavior patterns were altered and ducks were driven from land

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
				into the water by the disturbance. Surf scoters appeared to be more sensitive than oldsquaws. Surf scoters spent more time swimming and feeding (rather than resting) during disturbances than during periods of non-disturbance. Birds of all species tended to form tight flocks during disturbance. Flock sizes and numbers of birds in flocks (as a percentage of the total birds) increased as the disturbance continued.
Waterfowl	Schweinsburg, 1974	field observation	aircraft-Cessna 185 float plane	The waterfowl population on a 0.06 sq. mi. lake was reduced by 60% during four days of disturbance. Populations did not return to original level after disturbance. The waterfowl populations of a larger lake (0.10 sq. mi.) also declined but the data was inconclusive because of inconsistant counts.
Waterfowl	Schweinsburg, et al., 1974	field observation	aircraft-Cessna 185 float plane	Experiments of aircraft disturbance (float plane landing and taxiing) on two small lakes (.24 and .31 sq. mi) of which one was primarily used as a brood rearing lake and the other by molting and non-breeding waterfowl, resulted in a marked reduction in waterfowl numbers on the lake used by non-breeders. Females with broods did not appear to avoid the disturbance by flight as did the non-breeders. The most frequent reactions to aircraft disturbance by all species was to either dive or fly away.
Lapland longspurs (*Calcarius lapponicus*)	Gollop et al., 1974b	field observation	aircraft and human disturbance	No significant difference in lapland longspur population density was noted on control, human and aircraft disturbance sites. However, onset of nesting may have been delayed and fledging production per pair appeared to be reduced on disturbed sites. Fewer nestlings on disturbed sites survived a severe storm than on the control site. Higher mortality on disturbed sites was attributed to greater numbers of later hatched chicks (i.e. younger) and where ages were equal, to the possibility of disturbed chicks being in poorer condition prior to the storm.
Lapland longspur (*Calcarius lapponicus*)	Gollop et al., 1974a	field observation	gas compressor, noise simulator	The sound emitted by a gas compressor noise simulator had no measurable short-term effect on lapland longspurs breeding in the vicinity (0-550 yds). Since the simulator was installed after the majority of the birds had arrived, it is not known what effect a gas compressor would have on territory selection.
Bald Eagles (*Haliaeetus leucocephalus*)	Stalmaster and Newman, 1978	field observation	human presence, boat traffic	The authors concluded that wintering bald eagles can become habituated to moderate, routine human activities. However, the study also showed that human activity had a significant influence on the eagle's feeding behavior. The mere presence of humans disrupted their feeding behavior causing the birds to abandon the feeding area for several hours until the disturbance no longer persisted. Activities occurring directly on the channel of the river studied, such as boating and fishing, were the most disturbing if they varied from normal activity patterns.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
OTHER				
Nearshore waters	Maline and Mlawski, 1978	field observation	underwater noise from drilling rigs	Test to determine underwater noise levels from drilling rigs indicated that very little noise was transmitted to the under-ice environment from the two drilling locations studied. Most of the noise decayed rapidly within .5-1.0 miles from the rig. Some low frequency sound (30 Hz) could be detected with sophisticated equipment at 4-6 mi. In open water conditions, 5 Hz component from Reindeer drilling rig might be detectable up to 5 mi. seaward.

Sensitivity of Areas and Recommended Mitigative Measures

Areas in the northern Bering Sea and Norton Sound were ranked as having a low, moderate, or high sensitivity to the impacts of noise and disturbance (see Map B). These designations were based on existing data and were made after evaluating the following criteria.

1. The sensitivity of each fish and wildlife species or habitat to noise and disturbance.

2. Species sensitivity to noise and disturbance during the various stages of their life history.

3. The time of year that these critical life history stages occur and the period during which each species would be most affected.

4. The location of habitats where critical life history stages occur.

5. The productivity of the habitat.

6. The uniqueness of the habitat.

7. The species' population numbers and relative importance of the population.

8. The degree to which the impacts of noise and disturbance could be mitigated.

Specific considerations and assumptions that were made during the course of ranking included:

1. Birds and mammals would be most affected by the adverse impacts of noise and disturbance. Blasting would be the only disturbance which would affect fish populations.

2. Sensitive bird and mammal species would be most affected by long-term noise and disturbance. Short-term or occasional disturbances would be less disruptive and could be mitigated by careful timing or siting of the activity.

3. Species most affected by the adverse impacts of noise and disturbance would be those in which the disturbance results in direct mortality or abandonment of breeding grounds (nesting birds) or those species which are confined to a discrete habitat during a critical life history stage (marine mammals on haulouts).

4. Moderate sensitivity designations were applied to those areas where it was felt that the adverse impacts of noise and disturbance on a species or life stage could be mitigated or prevented by careful siting or timing of activities. Also

included in this category were areas utilized by sensitive species during a critical life history stage but which were large enough to allow siting of activities away from nest sites, etc. Salmon spawning streams, raptor nesting areas, moose and grizzly bear concentrations along streams, and marine mammal and seabird harvest areas are included in moderate sensitivity designations.

5. Possible polar bear denning areas were ranked as being moderately sensitive because actual denning has not been verified. The presence of polar bears on St. Lawrence Island (site of the possible denning) is not a yearly occurrence but is dependent upon ice conditions. Areas habitually used by denning polar bears would be ranked as highly sensitive to noise and disturbance.

Sensitivity Designations and Mitigative Measures

LOW SENSITIVITY AREAS

The designation of low sensitivity was given to areas where impacts on fish and wildlife from noise and disturbance would be less adverse than in moderate or high sensitivity areas. Activities causing noise and disturbance in low sensitivity areas should be conducted in compliance with existing environmental regulations such as Federal noise level standards and Federal Aviation Administration flight regulations.

MODERATE SENSITIVITY AREAS

The designation of moderate sensitivity was given to areas where adverse impacts from noise and disturbance could be prevented, minimized, or ameliorated. Habitats included in the moderate sensitivity category are:

1. Salmon streams
2. Waterfowl and shorebird spring concentration areas
3. Raptor nesting areas
4. Marine mammal feeding and migration areas including: ringed seal important habitats and high density areas; belukha whale and gray whale feeding areas; belukha whale, gray whale, and bowhead whale migration areas; and walrus calving, migration, and wintering areas; and, belukha whale calving areas
5. Polar bear denning sites (possible) and migration routes
6. Grizzly bear spring feeding areas and prime summer habitat
7. Moose overwintering areas
8. Muskox overwintering and calving concentration area
9. Belukha whale, bowhead whale, waterfowl, seabird and seal subsistence harvest areas

The following mitigating measures should be employed when conducting activities causing noise and disturbance in areas ranked as being moderately sensitive to noise and disturbance.

General Mitigations

1. Facilities should be sited away from highly sensitive habitats (see Map B).

2. Noise generating activities such as helicopter and boat traffic, blasting or construction should be scheduled at times and places when there will be minimal impacts on fish and wildlife. Schedule activities in sensitive areas to non-sensitive times (see Table 5).

Facility Siting

1. Site facilities with high levels of visual and acoustical disturbance away from biologically productive areas (sound levels decrease with distance).

2. Facilities should be sited a minimum of one mile away from critical habitats such as seabird colonies and peregrine falcon nesting cliffs.

3. Site facilities where physical barriers such as irregular terrain will prevent sound and visual impacts from occurring over a wide area.

4. Provide vegetative buffer zones around facilities. Indigenous vegetation should be left during the site clearing wherever possible.

5. Use machinery that produces less noise, i.e. modify the design of equipment to reduce noise; equip machinery with parts such as mufflers that will reduce noise.

6. Conduct activities with high levels of acoustical and visual disturbance during periods of least biological activity.

Helicopters and Fixed-Wing Aircraft

1. Helicopters and fixed wing aircraft should maintain a vertical distance of at least 1,500 feet, and a horizontal distance of one mile from sensitive areas during critical life history stages (see Table 5).

2. Under no circumstances should flights over sensitive areas be less than 500 feet. VFR flights over sensitive areas such as seabird colonies, should be cancelled when ceilings below 500 feet have been reported by flight service stations or other pilots. Wildlife observed while flying at 500 feet should be avoided by a one-quarter mile horizontal distance.

3. During all phases of oil and gas development, aircraft, especially helicopters, should follow fixed flight paths which avoid sensitive areas during critical times.

4. If flights over sensitive habitats cannot be avoided during critical periods, the number of aircraft flying over these areas should be minimized.

5. Rapid, linear flight over animals causes less disturbance than circling. Under no circumstances should helicopters unnecessarily hover or circle over animals.

6. If flight over a bird nesting cliff during the breeding season becomes necessary due to weather or other unavoidable circumstances, aircraft should approach the cliff as directly as possible. An approach from behind the cliff may result in the sudden appearance and sound of an aircraft directly above the nesting site, causing panicked flight by the attending adults and fatal damage to the eggs or young.

7. Helicopter and fixed-wing aircraft landing areas should be located at a sufficient distance from sensitive areas so that minimum altitudes can be attained before aircraft overfly any sensitive areas.

8. Orientation classes should be conducted for all new pilots to aquaint them with the long term effects of aircraft disturbance on wildlife populations and State laws relating to harassment of wildlife.

9. In order to establish effective aircraft operation restrictions in sensitive areas, specific studies need to be conducted on of the effects aircraft disturbance on a variety of mammals and birds found in the Norton Sound-Bering Sea region.

Boats

1. Boats engaged in oil and gas exploration, development, and production should maintain a distance of at least one mile from sensitive areas during critical periods (see Table 5).

2. Oil support activities (such as gravel supply barges, supply boats, and tankers) should avoid all marine mammal concentrations during critical periods.

3. Sirens or horns should not be used near bird colonies or marine mammal haulouts.

4. Navigational aids such as foghorns, or flashing lights should not be placed in or near seabird colonies or marine mammal haulout areas.

Seismic Exploration

1. Seismic exploration should be conducted using only non-explosive techniques which do not physically harm fish and wildlife.

2. If a situation arises where non-explosive techniques cannot be used, and underwater blasting is necessary to protect human life, prevent environmental damage, or protect property, blasting programs should be designed to reduce energy transmitted to the surrounding waters. Techniques such as blast curtains, small delayed charges, jetted charges, etc. will minimize environmental damage from blasting.

3. To protect ringed seals and marine fish, under-ice pressures from explosive detonations on the ice should not exceed 3 psi.

4. Terrestrial blasting should be: 1) conducted during nonsensitive periods; 2) limited in favor of mechanical methods wherever possible and desirable; and 3) conducted with reduced charges, timed delays or muffled in other ways to reduce noise transmission to surrounding areas.

5. Where possible, there should be coordination of seismic programs among operators to minimize duplication. Overlapping or duplicate seismic programs by various companies can intensify and prolong the disturbance in an area.

6. Onshore seismic activity should be conducted during the winter months when overland travel causes the least damage to the tundra. Winter is also the period of lowest biological sensitivity for most wildlife species. Vehicular traffic should be restricted to the immediate area of operations.

7. No seismic surveys should be conducted in the shorefast ice zone after March 20. Ringed seals begin pupping and rearing young after this date. Along the Beaufort Sea coast, ringed seal abundance in areas where seismic exploration has occurred is only one-half to one-third that of undisturbed areas.

8. In the shorefast ice zone, seismic shot lines should be spaced at intervals of no less than two miles, or the areas of seismic exploration should be as restricted as possible.

9. Seismic surveys should maintain a minimum distance of one mile from sensitive habitats during sensitive periods (see Map B). Explosives should not be used within two miles of peregrine falcon nests during the period of April 15 to August 31.

10. Explosives detonated near a fish bearing waterbody should be detonated at a sufficient distance so that induced water pressures within the waterbody do not exceed 2 psi. The following table provides minimum stream setbacks for various substrate types and charge sizes.

CHARGE WEIGHT - POUNDS

DISTANCE TO WATERBODY - FEET

Substrate	1	2	5	10	25	100	500	1000
Rock	53	75	118	167	269	529	1182	1671
Stiff Clay	42	60	95	134	211	423	946	1337
Gravel	41	59	93	131	207	414	927	1310
Clayey Silt Dense Sand	37	52	82	116	184	368	823	1163
Medium to Dense Sand	32	46	72	102	162	324	724	1024
Medium Organic Clay	21	29	46	66	104	207	463	655
Soft Organic Clay	19	28	43	61	97	194	435	615

These charge weights are for single detonations separated by at least 8 milliseconds from the next charge (i.e. if 1000 pounds of charge are detonated in 10 detonations of 100 pounds each, separated by at least 8 milliseconds, the distance for 100 pounds can be used as the minimum distance from the waterbody). The State of Alaska prohibits the use of high explosives for seismic work in lakes, steams, and marine waters of the State.

Human Presence

1. Human visitation to sensitive habitats during critical times should be restricted in order to maintain populations of wildlife.

2. All human activities should be prohibited within one mile of peregrine falcon nesting cliffs between April 1 and August 15.

3. Orientation classes for all employees, including management and supervisory personnel, should be required so as to inform personnel of the dangers, adverse biological consequences, and legal ramifications of animal feeding.

4. All management personnel should be taught proper garbage disposal methods in order to eliminate animal feeding.

5. Construction camps, garbage dumps and incinerators should be fenced and buildings skirted in order to minimize human and animal conflicts.

6. All edible garbage must be thoroughly incinerated or buried to prevent conflicts between humans and animals.

7. Regulations to minimize human and animal contacts must be developed and enforced. An effective regulation and enforcement program must be administered by personnel beyond the influence of contractors or unions. Companies should have policies which penalize violators.

8. Specific research on animal harrassment should be included as part of the design criteria for any oil and gas development plan wherever these activities will impact a sensitive area or a new species.

In order to implement these guidelines, site specific studies will have to be conducted on a case-by-case basis. In instances where information is not available regarding the effects of noise and disturbance on the various stages of animal life history, more research will have to be done to determine the extent of the problem.

HIGH SENSITIVITY AREAS

The designation of high sensitivity was given to habitats where impacts from noise and disturbance would be extremely adverse to wildlife populations. While all phases of oil and gas development will produce a certain amount of noise and disturbance, activities and facilities which produce year round disturbance will have a greater adverse impact on wildlife than those activities which occur only occasionally during the year.

Habitats included in the high sensitivity category are:

1. Seabird colonies and concentrations of seabirds at the base of colonies
2. Waterfowl and shorebird nesting, molting, and staging areas including: major and important staging areas; waterfowl and emperor geese molting areas; snow geese and emperor geese staging areas; swan nesting/use areas; sandhill crane use area; and important shorebird habitat
3. Peregrine falcon nesting/use areas
4. Marine mammal haulouts including: recurrent and occasional walrus haulouts, spotted seal haulouts and feeding areas; and sea lion haulouts
5. Moose winter concentration areas
6. Grizzly bear denning areas

In order to maintain wildlife populations, oil and gas facilities or other activities with a high level of disturbance which will continually disrupt the environment, should not be sited in areas which are highly sensitive to noise and disturbance.

TABLE 5: MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND SPECIES OR HARVEST ACTIVITIES ARE MOST SENSITIVE TO NOISE AND DISTURBANCE.

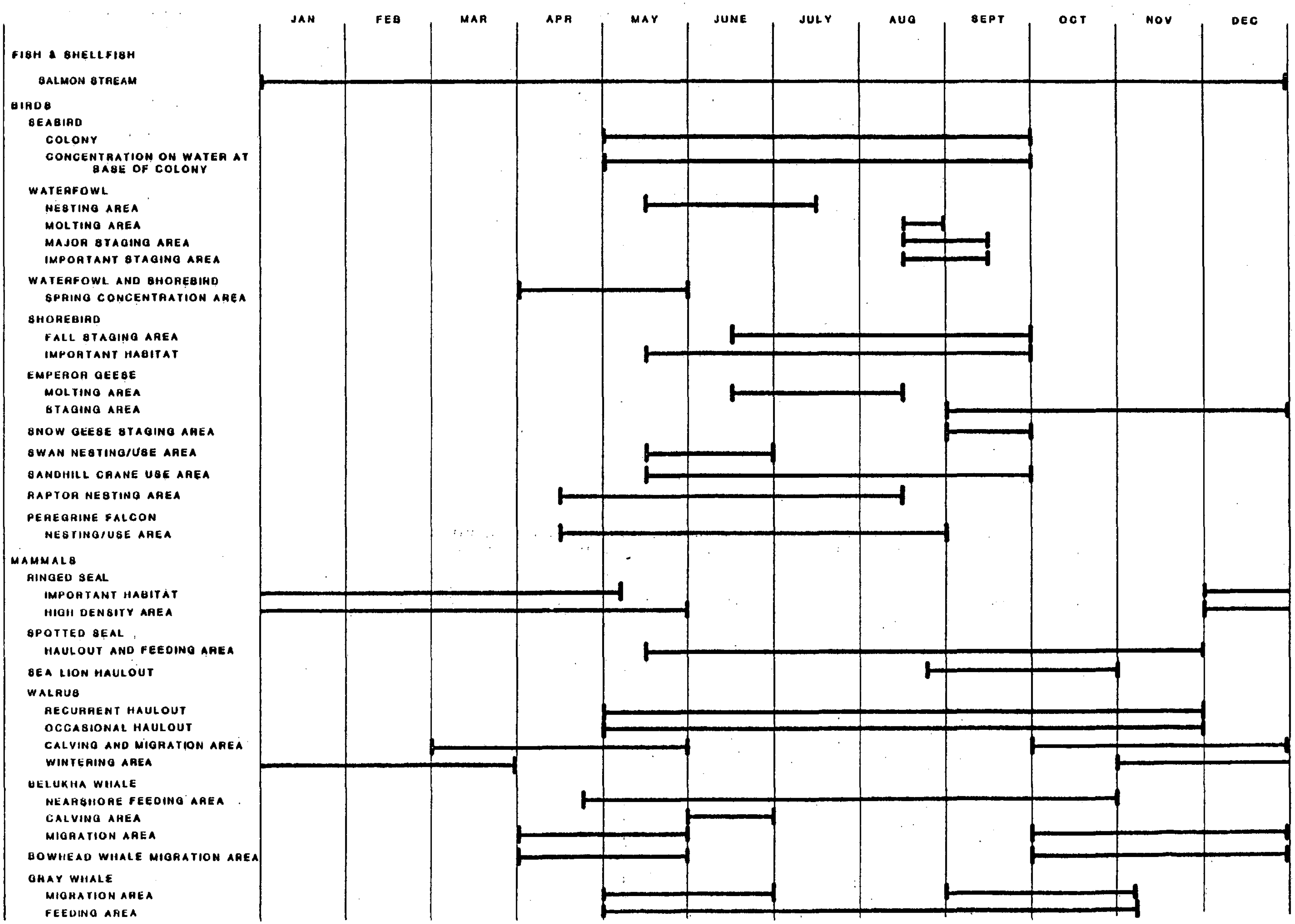
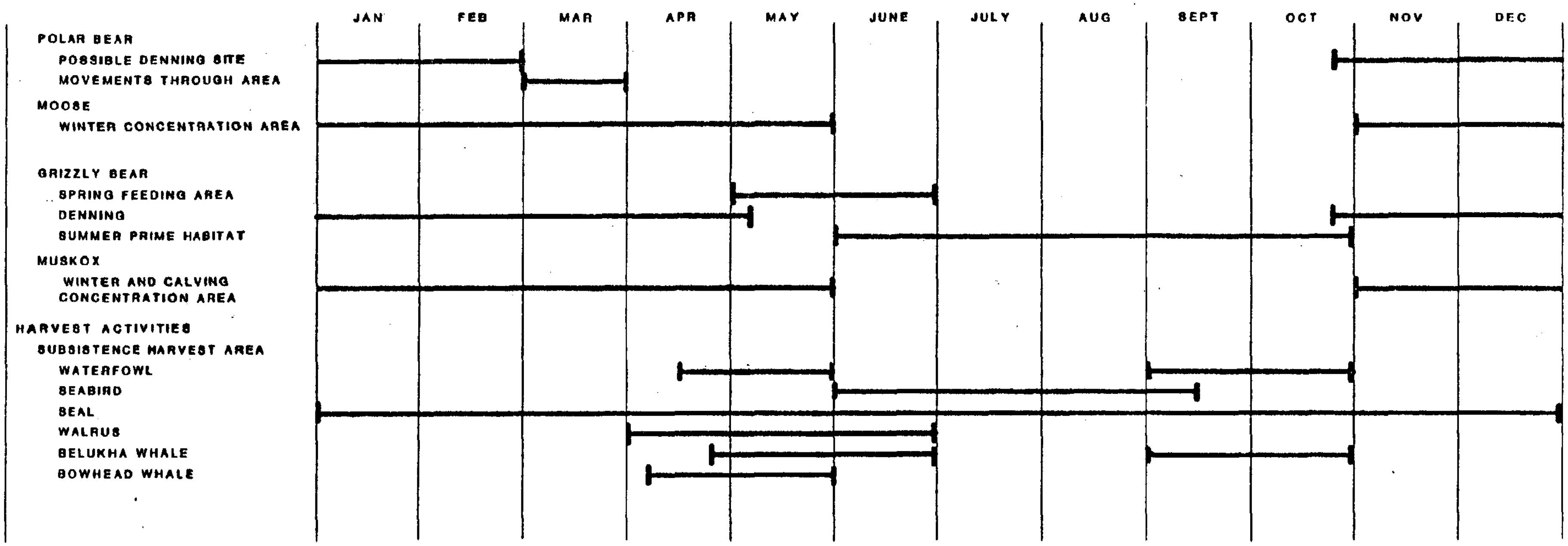


TABLE 5 : (CONT.) MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND SPECIES OR HARVEST ACTIVITIES ARE MOST SENSITIVE TO NOISE AND DISTURBANCE.



C

DRILLING MUDS & CUTTINGS

DRILLING MUDS AND CUTTINGS

Sources and Biological Effects

During the exploration and development phases of offshore oil and gas extraction, exploratory wells are first drilled to determine if oil and gas are present. If hydrocarbons are discovered in commercial quantities, platforms are erected and a number of development wells are drilled to extract hydrocarbons from an oil bearing formation. While drilling, adverse environmental impacts may result from the discharge of drilling muds and drill cuttings into marine waters. The extent of mud and cuttings discharge will vary in direct proportion to the depth and diameter of the hole being drilled. When drilling a very shallow well the total volume of mud and cuttings may only be 2,000 barrels; however, very deep wells may produce discharge volumes as high as 100,000 barrels (Moseley, 1980).

Drilling Muds

Drilling muds are special mixtures of clay, water (or oil) and chemicals which are circulated into the drilling hole to cool and lubricate the drill bit, to remove formation cuttings from the hole, and to prevent blowouts by holding back formation pressures exerted by oil and gas accumulations (McDermott & Co., undated). Throughout the drilling process muds are recirculated after cuttings and other debris are removed. Large volumes of mud are discharged into the marine environment usually after surface casings of wells have been set, or as the wells are completed

(Sheen Technical Subcommittee, 1976). In some cases, the muds are stored for future drilling activities once drilling terminates (Clark and Terrell, 1978).

Drilling fluids and their chemical components may at times be acutely toxic to fish and marine invertebrates. (Daugherty, 1951; Falk and Lawrence, 1973; B.C. Research, 1975; Tornberg et al., 1980). The effects of drilling muds on marine species are related to: a) the composition of the mud, b) the quantity and rate of mud discharged, c) the nature of the receiving waters, and d) the biological sensitivity of species present. It has additionally been reported that "used" muds (downhole circulated) are more toxic to marine species than "fresh" muds (laboratory aged), therefore, characteristics acquired by muds during the drilling process may also be a determining factor in toxicity (Thompson and Bright, 1980; McAuliffe and Palmer, 1976). Simple drilling muds without additives can be classified as representing low to moderately toxic compounds. Because of the relatively low toxicity of simple drilling muds, most adverse effects will result from the discharge of muds into shallow waters, water bodies with limited circulation or mixing, or waters containing high concentrations of eggs, larvae, or sensitive juvenile or adult organisms. Drilling muds which contain highly toxic additives to deal with specific drilling problems will be toxic under any circumstances, but the biological effects of these muds will be most severe in marine or freshwater areas where little dilution or mixing occurs.

The most commonly used components of water-based muds are barite, caustic soda, bentonite clays, and lignosulfonates. Of these, soda and lignosulfonates are usually considered the most toxic (Dames and Moore, 1978). Ferrochrome lignosulfonate, a heavy metal compound, may be freed by chemical reactions when released into the marine environment, resulting in contamination of surrounding waters and possible toxicity to aquatic organisms (Lawrence & Scherer, 1974). Heavy metals are often essential or non-toxic to organisms in low concentrations but become toxic in high concentrations. Even if the concentration of a heavy metal in water is not immediately lethal, it may accumulate in animal tissues until lethal levels are reached (NERBC, 1976). Heavy metal contamination can affect living organisms or ecosystems by 1) changing the species composition in the area where the effluent is discharged, 2) disrupting the biological systems of individual organisms, and 3) accumulating in members of the food chain until the predators in higher trophic levels are affected (APOA & Environment Canada, 1976). In drilling the Norton Sound COST well, chrome lignosulfonate in concentrations of 18,000-24,000 fluid parts per million were present in the mud mixture used (USGS, 1981).

Although barite and bentonite are not considered toxic to plants and animals they do contribute to the suspended solids content of a drilling mud and are of concern because upon discharge they increase the turbidity (cloudiness) of the surrounding water causing a slight decrease in the production of phytoplankton and macrophytes. Possible effects of suspended solids on organisms living in the marine environment include irritation of sensitive membranes, suffocation, decreased resistance to disease, behavorial changes, reduced rate of growth, increased oxygen demand, and changes in the development of juvenile fish (Dames and Moore, 1978).

Caustic soda is used primarily to reduce bacterial growth in drilling mud by maintaining a high pH (Dames & Moore, 1978). Studies have shown that caustic soda is lethal to various aquatic species in concentrations of 70 to 450 ppm (Daugherty, 1950). Falk and Lawrence (1973) recorded the LC50 for rainbow trout exposed to caustic soda at 105 ppm. Muds used in drilling the Norton Sound COST well contained caustic soda concentration mixtures of 600-5,000 fluid parts per million (USGS, 1981). In addition to barite, caustic soda, bentonite clays and lignosulfonates, drilling muds may contain other chemicals such as viscosifiers, emulsifiers, completion chemicals, thinners, and preservatives (see Table 6). Most of these chemicals are used in drilling deep wells or in dealing with special drilling problems. Although these special mud additives are rarely used in large quantities, many of them are extremely toxic (Table 7). Sodium pentachlorophenate (Dowicide G), a bactericide used in drilling fluids, is lethal to fish at 0.06 ppm (McKee and Wolf, 1963). Trivalent chromium salts which are generally used concurrently with XC polymers in drilling fluids are toxic to aquatic life at 0.3-1 ppm (Land, 1974). Hexavalent chromium, a major source of aquatic toxicity in drilling fluids, can occur in concentrations of up to 450 ppm in mud, and is harmful to aquatic biological systems at concentrations of 0.1 to 0.4 ppm (Land, 1974). Several highly toxic compounds are also used for lubrication and clearing in the drilling process, including Skot-Free, B-Free, Swift Rig Wash, and Dominion Rig Wash. Their 96 hour LC50 values for rainbow trout were 52, 19, 22, and 14 ppm respectively (Logan et al., 1973).

Another potential adverse impact resulting from the discharge of drilling muds occurs through an accumulation of muds on the bottom. Muds which settle to the bottom can smother benthic (bottom-dwelling) organisms which are incapable of moving out of a disturbed area (Dames & Moore, 1978). Mobile species might not be smothered, but still may be affected by a destruction of habitat or loss of food material (APOA & Environment Canada, 1976). Diesel oil or other chemicals added to muds to facilitate the drilling of deep wells can adhere to mud particles and settle to the bottom, thereby polluting the substrate. Filter feeding animals such as clams can filter out oil from sediments and concentrate it causing them to develop an unpalatable oily taste. St. Amant (1957) reported that as little as 500 ppm of oil in mud can cause adverse reactions in oysters, and 1 ppm of oil in a running water system will be concentrated by oysters kept at that concentration for several weeks.

Much of the literature presently available, attempts to establish lethal or acute toxic values rather than sub-lethal or behavioral responses to mud induced stress. Furthermore, studies have shown a wide variability regarding 96 hour LC50 values for whole drilling muds, whole mud extracts, and various mud components. This variability has made it difficult to establish 96 hour LC50 guidelines (see Table 7). Much of the variability can be attributed to experimental technique and dissimilar drilling fluid characteristics. Reported LC50 values for whole muds generally fall in the range of 10,000 to greater then 100,000 ppm (BLM, unpub. data a). In a study conducted by Dames and Moore (1978) using aquatic species of fish and marine invertebrates common to Cook Inlet, pink salmon fry were found to have the greatest susceptibility to drilling fluids, with 96 hour LC50 values ranging from 3,000 to 29,000 ppm. Tornberg et al. (1980), utilizing marine species from the Beaufort Sea

Table 6

Common Drilling Fluid Components

Description	Primary Application
	Weighting Agents And Viscosifiers
Barite	For increasing mud weight up to 20 lbs/gal.
Calcium Carbonate	For increasing weight of oil muds up to 10.8 lbs/gal.
Bentonite	Viscosity and filtration control in water base muds.
Sub-Bentonite	For use when larger particle size is desired for viscosity and filtration control.
Attapulgite	Viscosifier in salt water muds.
Beneficiated Bentonite	Quick viscosity in fresh water upper hole muds with minimum chemical treatment.
Asbestos Fibers	Viscosifier for fresh or salt water muds.
Bacterially Produced Large Organic Polymer	Viscosifier and fluid loss control additive for low solids muds.
	Dispersants
Sodium Tetraphosphate	Thinner for low pH fresh water muds.
Sodium Acid Phyrophosphate	For treating cement contamination.
Quebracho Compound	Thinner for fresh water and lime muds.
Causticized Quebracho	1-2 ratio caustic-Quebracho for thinning low pH fresh water muds.
Hemlock Extract	Thinner for fresh water muds and in muds containing salt (10,000 to 15,000 ppm).
Modified Tannin	Thinner for fresh and salt water muds alkalized for pH control.
Causticized Lignite	1-6 ratio caustic-lignite dispersant, emulsifier and supplementary fluid loss additive.
Calcium Lignosulfonate	Thinner for SCR and lime muds.
Modified Lignosulfonate	Dispersant and fluid loss control additive for water base muds.
Blended Lignosulfonate Compound	Dispersant, fluid loss agent and inhibitor for RD-111 mud systems.
	Fluid Loss Reducers
Pregelatinized Starch	Controls fluid loss in saturated salt water, lime and SCR muds.
Sodium Carboxymethyl Cellulose	For fluid loss control and barite suspension in water base muds.
Sodium Carboxymethyl Cellulose	For fluid loss control and viscosity building in low solids muds

Description	Primary Application
	Fluid Loss Reducers - Continued
Sodium Carboxymethyl Cellulose	For fluid loss control in gyp, sea water and fresh water muds.
Polyanionic Cellulosic Polymer	For fluid loss control and visosifier in salt muds.
Sodium Polyacrylate	For fluid loss control in calcium free low solids muds.
Sodium polyacrylate	For fluid loss control in low solids muds.
	Lubricants, detergents, emulsifiers
Extreme Pressure Lubricants	Used in water base muds to impart extreme pressure lubricity.
Processed Hydrocarbons	Used in water base muds to lower down-hole fluid loss and minimize heaving shale.
Oil Dispersible Asphalts	Used in water base muds to aid in controlling heaving shale.
Oil Soluble Surfactants	Used for spotting around differentially stuck pipe.
Detergent	Used in water base muds to aid in dropping sand. Emulsifies oil, reduces torque and minimizes bit balling.
Non-Ionic Emulsifier	Emulsifier for surfactant muds.
Blend of Anionic Surfactants	Emulsifier for salt and fresh water muds.
An Organic Entity Neutralized with Amines	Non-Polluting Lubricant for water base muds.
Blend of Fatty Acids Sulfonates, Asphaltic Materials	Used for spotting around differentially stuck pipe where weights in excess 10 ppg are required.
	Defoamers, Flocculants, Bactericides
Aluminum Stearate	Defoamer for lignosulfonate muds.
Sodium Alkyl Aryl Sulfanate	Defoamer for saturated salt muds.
Flocculating Agent	Used to drop drilled solids where clear water is desirable for a drilling fluid.
Paraformaldehyde	Prevents starch from fermenting when used in muds of less than saturation or alkalinity less than 1 cc.
Sodium Pentachlorophenate	Bactericide used to prevent fermentation.
	Lost Circulation materials
Fibrous Material	Filler as well as matting material.

Description	Primary Application
	Lost Circulation Materials - Continued
Fibrous Mineral Wool	Often used in areas where acids are later employed to destroy the material.
Walnut Shells-	
Fine	Most often used to prevent lost circulation.
Medium	Used in conjunction with fibers or flakes to regain lost circulation.
Coarse	Used where large crevices or fractures are encountered.
Ground Mica-	
Fine	Used for prevention of lost circulation.
Coarse	Forms a good mat at face of well bore.
Cellophane	Used to regain lost circulation.
Combination of granules, flakes and fibrous materials of various sizes in one sack.	Used where large crevices or fractures are encountered.
Blended high fluid loss soft plugging material	One sack mixture for preparing soft plugs for severe lost circulation.
	Specialty Products
Shale Control Reagent	Calcium chloride mud for inhibiting the swelling of bentonitic shales.
Bentonite Extender	Increases yield of bentonite to form very low solids drilling fluid.
Non-Ionic Surfactant	Primary surfactant for formulating surfactant muds. May be used in hot holes for viscosity stability.
Filming - Amine	Corrosion inhibitor.
	Commercial Chemicals
Sodium Chromate	Used in water base muds to prevent high temperature gelation and as a corrosion inhibitor.
Sodium Hydroxide	For pH control in water base muds.
Sodium Carbonate	For treating out calcium sulfate in low pH muds.
Sodium Bicarbonate	For treating out calcium sulfate or cement in high pH muds.
Barium Carbonate	For treating out calcium sulfate (pH should be above 10 for best results).
Calcium Sulfate	Source of calcium for formulating gyp muds.
Calcium Hydroxide	Source of calcium for formulating lime muds.

Description	Primary Application
	Commercial Chemicals - Continued
Sodium Chloride	For saturated salt muds and resistivity control.
Potassium Hydroxide	For pH stability and inhibition.
Chrome Alum (chromic chloride)	For use in cross-linking XC Polymer systems.
	Oil Base and Invert Emulsion Muds
Invert Emulsion (Water in Diesel Oil)	Protects sensitive producing formulations.
Oil Base Mud	Basically same application as Ken-X.
Gelatinous Oil Base Fluid	For casing recovery, corrosion control and protection of fresh water sands.
	Emulsifiers for Invert Emulsions
Primary Emulsifier	Primary additives to form stable water-in-oil emulsion.
Viscosity and Gel Builder	Provides weight suspension.
Hi-Temperature Stabilizer	Improves emulsion under high temperature conditions.
Hi-Temperature Stabilizer	Improves emulsion, weight suspension and fluid loss under high temperature conditions.

Source: BLM, 1978

Table 7
Summary of Published Drilling Fluid Component Toxicities
(Adapted from: McAuliffe and Palmer, 1976
BLM, unpub. data a)

Test Material	Bioassay1/ Media	Test Organism	Toxicity LC50-96 2/, ppm 3/ (Unless Otherwise indicated)	Reference
Adgo F28	F	Rainbow trout	480,000	Beak Consultants, 1974
Aluminum Sterate	F	Rainbow trout	1,100	Beckett et al., 1975
Ammonium phosphate	F	Rainbow trout	100 (toxic)	Beck Consultants, 1974
Ammonium sulphate	F	Rainbow trout	100 (toxic)	
Aqugel (Wyoming Bentonite)	M	American oyster	7,500 (nontoxic)	Daugherty, 1957
Barite	M	American oyster	50-60 (LC50-216)	
	M	Various organisms	7,500	Daugherty, 1957
	F	Sailfin molly	100,000	Grantham and Sloan, 1975
	M	Sailfin molly	100,000	Grantham and Sloan, 1975
	F	Rainbow trout	7,500 (threshold LC50)	Falk and Lawrence, 1973
	F	Rainbow trout	24,000	Beak Consultants, 1974
Barite fluid extract	F	Rainbow trout	nontoxic	Shaw, 1975
Bark extract modified hemlock	M	White shrimp	265	Chesser and McKenzie, 1975
Baroyd	M	American oyster	nontoxic	Daugherty, 1957
Ben-Ex	F	Rainbow trout	527-836*	Falk and Lawrence, 1973
Bentonite	F	Rainbow trout	10,000	Falk and Lawrence, 1973
Bentonite	M	American oyster	110-119 (LC50-192 day)	Cabrera, 1968
Bentonite fluid extract	F	Rainbow trout	28,570 (nontoxic)	Shaw, 1975
	M	Sailfin molly	100,000	Grantham and Sloan, 1975
Calcium chloride	F	Water Flea (Daphnia)	920 (Threshold immobilization)	Anderson, et al., 1948
Calcium chloride	F	Mosquito Fish	13,400	Wallen et al., 1957
Calcium chloride	F	Bluegill	10,650	Williams and Jones, 1975
Capryl alcohol	F	Rainbow trout	56-100*	Falk and Lawrence, 1957
Carbonox (lignitic material)	M	Various organisms	7,500	Daugherty, 1957
	F	Rainbow trout	1,300	Beckett et al., 1975
Carboxy methyl cellulose, regular	F	Rainbow trout	10,000	Falk and Lawrence, 1975
Carboxy methyl cellulose, Hi-Vis	F	Rainbow trout	10,000	Falk and Lawrence, 1975
Caustic soda (NaOH)	F	Rainbow trout	730	Logan et al., 1973
Cellulose-Calcium carbonate workover additive	M	White shrimp	1,925	Chesser and McKenzie, 1975
Cement (oil well)	M	Various organisms	70-450	Daugherty, 1957
Chromate Cr+6, soft water	F	Mosquito fish	107	Wallen et al., 1957
Chrome lignosulfonate	F	Sailfin molly	7,800	Daugherty, 1957
Chrome lignosulfonate	F	Rainbow trout	5,600	Deak Consultants, 1974
Chrome lignosulfonate	M	White shrimp	465	Chesser and McKenzie, 1975
Chrome lignosulfonate	M	Sailfin molly	12,200	Hollingsworth and Lockhart, 1975
Crude oil	F	Rainbow trout	400 (lethal)	Shaw, 1975
Cypan	F	Rainbow trout	1,200-1,300	Beckett et al., 1975
Desco	F	Rainbow trout	1,200	Beckett et al., 1975

Test Material	Bioassay[1/] Media	Test Organism	Toxicity LC50-96[2/], ppm [3/] (Unless Otherwise indicated)	Reference
Dextrid	F	Rainbow trout	1	Beckett et al., 1975
Diatomaceous earth fluid extract	F	Rainbow trout	14,285 (not lethal)	Shaw, 1975
Dichromate Cr+6 hard water	F	Bluegill	133	Logan et al., 1973
Dichromate Cr+6 soft water	F	Mosquito fish	100	Wallen et al., 1957
	F	Bluegill	118	Falk and Lawrence, 1973
Dodecyl sodium sulphate	F	Rainbow trout	5-7	Beak Consultants, 1974
Dominion rig wash	F	Rainbow trout	10-18	Falk and Lawrence, 1973
Dowicide-B	F	Rainbow trout	0.75	Beckett et al., 1975
Ferrochrome lignosulfonate	M	Rainbow trout	1,140-2,050	Falk and Lawrence, 1973
Fibertex	M	Various organisms	7,500	Daugherty, 1957
Formaldehyde	F	Water Flea (Daphnia)	2 (48-hr threshold conc.)	McKee and Wolf, 1963
Formaldehyde	M&F	Salmon	26 (critical)	McKee and Wolf, 1963
Gilsonite, powdered	F	Rainbow trout	100 (nontoxic)	Shaw, 1975
Gypsum	F	Rainbow trout	756,000	Falk and Lawrence, 1973
Imperes (progelantinized starch)	M	Various organisms	500-7,500	Daugherty, 1957
Iron Carbonate (siderite)	F	Sailfin molly	10,000	Grantham and Sloan, 1975
Iron lignosulfonate	M	White shrimp	2,100	Chesser and McKenzie, 1975
Jelflake (shredded cellophane)	M	Various organisms	7,500	Daugherty, 1957
Kelzan-XC(polymer Xanthum gum)	F	Rainbow trout	100-560*	Falk and Lawrence, 1973
Lignite	F	Sailfin molly	24,500	Hollingsworth and Lockhart, 1975
Lignite	M	Sailfin molly	15,000 (100%survival)	Hollingsworth and Lockhart, 1975
Lignosulfonate thinners	F	Rainbow trout	100 (toxic)	Shaw, 1975
Metso beads	F	Rainbow trout	100-560*	Falk and Lawrence, 1973
Mica (mica flakes)	M	Various organisms	7,500	Daugherty, 1957
Montmorillonite clay	F	Water flea	100 (toxic)	Robinson, 1957
Oilfos (sodium tetraphosphate)	M	Various organisms	7,500	Daugherty, 1957
Paraformaldehyde	F	Rainbow trout	46-78*	Falk and Lawrence, 1973
Phosphoric acid ester disperant	F	Rainbow trout	10 (toxic)	Shaw, 1975
polyacrylamide bentonite flocculent	F	Rainbow trout	100 (nontoxic)	Shaw, 1975
Polyacrylate, low molecular wt.	M	White shrimp	3,500	
Potassium chloride	F	Water flea (Daphnia)	432 (threshold conc.)	Anderson et al., 1948
	F	Water flea (Daphnia)	317 (LC50-48)	Beisinger and Christensen, 1972
Potassium chloride	F	Mosquito fish	920	Wallen et al., 1957
Potassium chloride	F	Bluegill	2,010	Dowden and Bennett, 1965

Test Material	Bioassay[1/] Media	Test Organism	Toxicity LC50-96[2/], ppm [3/] (Unless Otherwise indicated)	Reference
Potassium chloride,	F	Rainbow trout	1,920-2,090*	Falk and Lawrence, 1973
Potassium chloride, reagent grade	F	Rainbow trout	1 (lethal)	Shaw, 1975
Potassium chromium sulphate	F	Rainbow trout	560-1,000*	Falk and Lawrence, 1973
Potassium chromic sulphate Cr+3, soft water	F	Bluegill	8.5	Pickering and Henderson, 1966
Potassium chromic sulphate Cr+3, hard water	F	Bluegill	72	Pickering and Henderson, 1966
Quadrafos	M	Various organisms	500-7,500	Daugherty, 1957
Quebracho	F	Sailfin molly	135	Hollingsworth and Lockhart, 1975
Rig wash compound	F	Rainbow trout	7,200 (lethal)	Shaw, 1975
Skot-free	F	Rainbow trout	36-76*	Falk and Lawrence, 1973
Sodium acid pyrophosphate	F	Various organisms	500 (toxic)	Daugherty, 1957
Sodium acid pyrophosphate	F	Sailfin molly	1,200	Hollingsworth and Lockhart, 1975
Sodium bicarbonate	F	Rainbow trout	7,500	Falk and Lawrence, 1973
Sodium chloride	F	Water flea (Daphnia)	3,660 (threshold conc.)	Anderson et al., 1948
	F	Water flea (Daphnia)	4,625	Beisinger and Christensen, 1972
Sodium chloride	F	Mosquito fish	17,550	Wallen et al., 1957
Sodium pyrophosphate	F	Rainbow trout	662-1,140	Falk and Lawrence, 1973
Spersene	F	Rainbow trout	2,500-5,000	Beckett et al., 1975
Sump fluid, composite	F	Lake chub	225,000	Falk and Lawrence, 1973
Sump fluid, surface	F	Lake chub	810,000	Falk and Lawrence, 1973
Swift's rig wash	F	Rainbow trout	11-41*	Falk and Lawrence, 1973
Visbestos	F	Rainbow trout	2,730	Beckett et al., 1975

1/ F = Freshwater
M = Estuarine or marine water
2/ LC50-X = lethal or median concentration giving 50% mortality in X hours
3/ ppm is mg/l * range of 95% confidence level
* range of 95% confidence level

reported that fish were the most sensitive species tested, and that invertebrates included both sensitive and relatively resistant species. For invertebrates, 96 hour LC50 values ranged from 310,000 to greater than 700,000 ppm for isopods, snails and polychaetes; 221,000 to 381,000 ppm for amphipods; and less than 60,000 to 215,000 ppm for mysids. Ninety-six hour LC50 values for all fish tested (fourhorn sculpin, broad whitefish, Arctic cod, saffron cod and Arctic cisco) ranged between 40,000 and 400,000 ppm. The authors further suggest some correlative relationship exists between the type of drilling fluid used, the depth of the well, and the measured acute toxicity. Hrudey (1979), evaluating the acute toxicity of wastewater from exploratory drilling operations, reported that surface hole and bottom hole muds are generally more toxic than intermediate hole muds. The acute toxicity associated with surface hole mud is apparently due to potash content. The bottom hole mud toxicity is attributed to lignosulfonates and barites. In most instances dilution within the water column should significantly decrease the toxicity of most drilling fluids except in areas very near their point of discharge. Conversely, some components such as bactericides and heavy metals are extremely toxic to marine species, and may accumulate in the water column or underlying sediments if sufficient current or tidal mixing is not available to disperse them.

A number of field studies have attempted to quantify the extent of heavy metal accumulation around active drilling rigs and assess the effects on benthic communities. In California, a study conducted by Ecomar Inc. (1978) in the Tanner Bank offshore area reported pre-drilling background levels of barium in sediment ranged from 8.7 to 156.0 mg/kg; chromium was recorded at less than 7.0 mg/kg; and lead concentrations ranged from 0.3 to 1.8 mg/kg. Post-drilling levels revealed barium levels ranging between 173 and 1680 mg/kg; chromium from less than 0.5 to 6.11 mg/kg; and lead varied from less than 0.7 to 9.9 mg/kg. A water sample taken 0.75 kilometers (.46 miles) from the discharge pipe contained over 10 times the background concentration of lead and chromium and over 5 times as much barium during a fluid discharge rate of 754 bbl/hr. A sample taken 2-3 meters (6.5 to 9.8 feet) from the pipe was about 500 times higher in lead and barium, and the chromium concentration was 1000 times background levels (Liss et al., 1980). Another study by Mobile Oil in the East Flower Garden Bank found increases in barium (from 22 to 425 ppm), iron (from 8.5 to 13,000 ppm), and lead (from 4.6 to 12.7). Generally, increased metal concentrations are usually confined to within 200 to 500 meters (656 to 1640 feet) of a drilling site (BLM, unpub. data a).

The results of studies into the effects of drilling fluids on benthic communities are contradictory and sometimes inconclusive. This variablility is probably due to the unique physical parameters associated with each drill site (oceanography, geology, etc.), the composition and volume of mud discharged, and the type of species present. In some instances drilling fluids may depress benthic species density or biomass values in the near vicinity of a discharge (Crippen and Hood, 1980), or they may influence the surrounding benthic composition by selectively enhancing or degrading a particular species habitat (Menzie et al., 1980). In most cases the discharge of drilling muds in deep, well mixed waters will not present the problems that occur in shallow marine and freshwater areas where toxic components may accumulate in the water column or sediment. Mud discharges in areas of intermediate depth are likely to be variable in their effect, and further research will be needed in order to resolve questions concerning the extent of their toxicity under such conditions.

Drill Cuttings

Drill cuttings, composed of bottom sediments and pieces of pulverized rock from underlying sedimentary geologic formations, are produced during the course of drilling a well. These materials along with some associated drilling muds are then discharged into surrounding waters. Because of their coarseness most cuttings will rapidly settle out from the discharged material and collect on the bottom near the point of discharge. The extent to which they accumulate and form piles will depend on current speed in the drilling area, although wave energy may also be an important factor. In shallow marine waters where currents are low (less than 0.25 knots) discharged cuttings have been reported to accumulate as mounds approximately 46 m (150 ft) in diameter (Zingula, 1976), and up to 6m (20 ft) in height (Carlisle et al., 1964). The volume of cuttings discharged from a platform will depend upon the depth of a well and the number of wells drilled. A shallow well will produce less cuttings than a deep well, and a single exploratory well will produce considerably less cuttings than a producing platform where as many as 20-30 wells may be drilled during the life of a field. Using 2 million pounds of cuttings as an average per well, 40-60 million pounds of cuttings may be discharged from a production platform. If sediment transport processes are weak these cuttings will be deposited in a small area surrounding the discharge pipe, but if currents are strong the cuttings may be thinly distributed over several square miles.

Clean drill cuttings are non-toxic and their primary effect on the aquatic environment will be a smothering of non-mobile benthic organisms such as clams, anemones and marine plants. When cuttings accumulate to more than 5 centimeters (2 inches) in depth it is likely that benthic infauna (organisms living within the bottom substrate) and less mobile epifauna (organisms living on the surface of the bottom substrate) will be severely affected (Dames & Moore, 1978). If a drilling platform happened to be sited in a unique ecological location such as a larval king crab settling area (which are usually limited in both size and number, and presently remain unidentified in this region), and the cuttings pile covered it, the negative effect could be significant.

Studies have further revealed that cutting piles may be colonized by a variety of marine organisms such as fish and crabs which use the hard substrate as a habitat (Menzie et al., 1980). If cuttings are deposited on a sandy or silty bottom, the character of this newly formed benthic community may differ from the already established, natural community (Dames & Moore, 1978). Drill cuttings which are not adequately cleaned before discharge may be contaminated with drilling muds and chemicals, or with hydrocarbons from the producing formation. The toxicity of these cuttings and their effect on the marine environment will generally be the same as the contaminating compound, and their disposal should be handled similarly.

Table 8 Effects of drilling muds and cuttings on fish, wildlife, aquatic plants and their habitats

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
FISH					
SALMONIDS					
Acute/Toxic Effects					
Pink Salmon Fry (Oncorhynchus gorbuscha)	Dames & Moore, 1978	static bioassay	drilling fluids	0.1-0.7% by volume	96 hr LC50's ranged from 0.3 to 2.9% by volume. Well stirred mixtures produced a much lower (0.3%) LC50 value than the same mud sample did with minimal stirring (2.9%). Pink salmon fry were the most sensitive species tested. With the mud tested, total suspended solids at the lowest LC50 equalled 1,100 mg/l.
Juvenile Rainbow Trout (Salmo gairdneri) Coho Salmon (Oncorhynchus kisutch) Chum Salmon (Oncorhynchus keta) Pink Salmon (Oncorhynchus gorbuscha)	Environment Canada, 1975	seawater bioassay	drilling fluid wastes	0-56% waste drilling fluids by weight	96 hr LC50 values for rainbow trout and coho salmon juveniles ranged from 1.6% to 19.0% v/v. Most were confined to the 1.6% to 3.9% v/v. There appeared to be a general trend for sample-specific toxicity. All 4 species showed similar tolerances when tested with a single sample (2.4-2.9% v/v) although pink salmon were slightly more tolerant (4.1%v/v).
Rainbow Trout (Salmo gairdneri)	Beak Consultants Limited, 1974a	static bioassay	drilling muds	5-25% drilling mud by weight	The 96 hr LC50's for rainbow trout ranged from 5.0% to 25.0% by weight. Filtrates of the drilling fluids were consistently less toxic than the whole mud systems. Source of toxicity was attributed to drilling components (muds) rather than drilled solids (cuttings). Toxicity was related to suspended solids and metalic ions contained in barites and lignosulphonates.
Rainbow Trout (Salmo gairdneri)	Beak Consultants Limited, 1974b	static bioassay	drilling fluids	9-27% drilling muds by weight	96 hr LC50's varied from 9.0% to 27.0% by weight. Increased toxicity (LC50's of 9.0% and 11.0%) was attributed to the addition of KCL and increased barite and lignosulphonate concentrations.
Rainbow trout (Salmo gairdneri)	Herbert & Wakeford, 1962	bioassay	calcium sulphate (gypsum)	3163-6820 ppm	Four weeks of exposure at pH value of 8.1 produced 50% mortality at 6,820 ppm gypsum (4,250 ppm in suspension); 3,163 ppm calcium sulphate (553 ppm in suspension) was not acutely toxic.
Rainbow trout (Salmo gairdneri)	Logan et al., 1973	bioassay	bentonite clay	10,000 ppm	Bentonite clay was not toxic to rainbow trout at 10,000 ppm after 96 hrs.

ppm = parts per million
ppb = parts per billion
LC50 = concentration required to kill 50% of the test animals
TLM = median tolerance limit - the concentration required to kill 50% of the test animals within certain time limits

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Rainbow Trout (Salmo gairdneri)	Herbert & Merkens, 1961	toxicity effects	mineral solid suspensions of kaolin and diatomaceous earth	30-810 ppm	Concentrations of 270 and 810 ppm of mineral solid suspensions of kaolin and diatomaceous earth produced high trout mortality after several months exposure. Gill damage (thickening and fusion of lamellae) was noted.
Rainbow Trout (Salmo gairdneri)	Herbert & Richards, 1963	bioassay	spruce fibre	50-200 ppm	Rainbow trout held in 200 ppm spruce fibre had mortalities of 50% after 16 weeks and 80% after 40 weeks. No deaths occurred at 50 ppm and 100 ppm.
Rainbow Trout (Salmo gairdneri)	Logan et al., 1973	bioassay	sodium acid pyrophosphate (SAPP)	870 ppm	96 hr LC50 for rainbow trout was 870 ppm at a pH of 6.25-6.5.
Rainbow Trout (Salmo gairdneri)	Logan et al., 1973	bioassay	lubricants and detergents	14-2,270 ppm	96 hr LC50 values for rainbow trout exposed to four water soluble surface active agents of unknown chemical composition (Scot-Free, B-Free, Swift's Rig Wash, and Dominion Rig Wash) were 52, 19, 22 and 14 ppm respectively. Tricron and Torq-Trim (surface wetting agents) had LC50's of 63 ppm and 2,270 ppm respectively.
Rainbow Trout (Salmo gairdneri)	Lawrence & Scherer, 1974	acute toxicity bioassay	mud from Imperial Oil's Immerk B-48 Beaufort Sea (Canada)	1-10,000 ul/l	The 96 hr LC50 values for rainbow trout were determined to be 75,000 ul/l.
Rainbow Trout (Salmo gairdneri)	Moore, Beckett & Weir, 1975	acute toxicity	drilling fluids-eight northern (Canada) drilling sites		Overall toxicity was a result of components in use at a particular time and the formation being drilled. Surface hole muds were most toxic (primarily from use of KCL to penetrate permafrost). Samples from greater depths exhibited multifactor toxicity (metals, solids and other compounds) compounded by high viscosity and extremely high solids content.
Rainbow Trout (Salmo gairdneri)	Weir, Lake, & Thackeray 1974	static bioassay	samples from drilling sumps in Canadian arctic	8.6%-100% by volume	The 96 hr LC50 ranged from 8.6% to 100% effluent concentration. Acute toxicity appeared directly related to concentrations of drilling compounds (Barytes and Peltex). Greatest toxicity appeared due to high concentrations of sodium, potassium chloride, chromium, and aluminum. There was evidence of gill chamber clogging and hemorrhaging of the gill chambers and eye area.
Physiological Effects					
Juvenile King Salmon (Oncorhynchus tshawytscha)	Olson, 1958		hexavalent chromium (CrO_4^{--}, $Cr_2O_7^{--}$)	0.2 ppm	Juvenile king salmon exposed to 0.2 mg/l of hexavalent chromium for 12 weeks showed reduced growth and increased mortality.
Pink Salmon Fry (Oncorhynchus gorbuscha)	NALCO, 1976	96 hr static bioassay	whole drilling muds, whole mud plus paraformaldehyde (0.25 lb/barrel mud)	10% mud	Dissolved oxygen concentrations in unaerated aquaria containing pink salmon fry decreased with time. Greatest decreases were observed at the higher concentrations of toxicants. No acute toxicity was observed at this concentration.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Brown Trout (*Salmo trutta*)	Herbert et al., 1961	field observations	suspended mineral solids	1,000 ppm	Brown trout populations in several rivers were severely reduced by 1,000 ppm china-clay wastes (containing mica, clay and sand in various proportions). Population reduction was due to cessation of reproduction, reduction of the aquatic invertebrate population and gill damage.
Rainbow Trout (*Salmo gairdneri*)	Herbert & Richards 1963	toxicity effects	spruce fibre bioassay	50-200 ppm	Rainbow trout growth was reduced by 20-40% after 40 weeks exposure to 50 and 100 ppm spruce pulpwood.
Behavioral Effects					
Rainbow Trout (*Salmo gairdneri*)	Lawrence & Scherer, 1974	behavioral	mud from Imperial Oil's Immerk B-48 Beaufort Sea and supernatent fraction	sublethal	Response to mud suspensions and the supernatent fraction was neutral at 100 ml/l shifting to preference at 1000 ml/l. Avoidance was observed at 10,000 ml/l of supernatent.
OTHER FISH					
Acute/Toxic Effects					
Whitefish (*Coregonus clupeaformis*)	Lawrence & Scherer, 1974	acute toxicity bioassay	mud from Imperial Oil's Immerk B-48 Beaufort Sea	25,000 ul/l	The 96 hr LC50 for whitefish was 25,000 ul/l.
Staghorn Sculpin (*Leptocottus armatus*)	Dames & Moore, 1978	static bioassay	drilling fluids	5-20% by volume	Based on a small sample and limited number of organisms, the 48 hr LC50 value for staghorn sulpin was 10-20% by volume.
Bluegill (*Lepomis macrochirus*)	Pruitt et al., 1977	bioassay and tissue accumulation	pentachlorophenol (PCP)	LC50 and sublethal	The 96 hr median lethal concentration (LC50) was 0.3 mg PCP/l for bluegill. Fish exposed to sublethal concentrations (0.1 mg/l) accumulated PCP in various tissues from 10 to 350 times the ambient concentration. The liver had the greatest concentration followed by the digestive tract, gills and muscles. Upon removal from PCP-contaminated water the fish rapidly eliminated PCP. Residues ranging from 0.03 to 0.6 ppm were still detectable, however, 16 days after fish were placed into a clean environment.
Physiological Effects					
Starry Flounder (*Platichthys stellatus*) Coho Salmon (*Oncorhynchus kisutch*)	Varanasi, 1978	bioassay-partial flow through	cadmium and lead	150 ppb	Starry flounder and coho salmon exposed to 150 ppb cadmium and lead in seawater at 10° and 4°C accumulated concentrations of these metals in the skin, mucus, brain, posterior

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
					kidney, and liver. Greatest accumulations occurred at 10°C, however depuration in starry flounder was slower at 4°C. Coho salmon tissues still retained 50% of the accumulated metals 37 days after removal to clean water. Lead was retained by both species in higher concentrations than cadmium.
Behavioral Effects					
Whitefish (Coregonus clupeaformis)	Lawrence & Scherer, 1974	behavioral	mud from Imperial Oil's Immerk B-48 Beaufort Sea and supernatent fraction	Sublethal 1 to 17,600 ml/l	Whitefish showed increasing attraction to mud suspensions with increasing concentrations (1-1000 ml/l). An increase in swimming speed was also observed. Response to supernatent was neutral at 55 ml/l, preference at 1000 ml/l, neutral at 10,000 and a tendency toward avoidance at higher concentrations (17,600 ml/l).
SHRIMP					
Pandalid Shrimp (Pandalus hypsinotus)	Dames & Moore, 1978	static bioassay toxicity effects	drilling fluids	8.6-20% by volume	Mortalities of pandalid shrimp at 20% concentrations (LC50-8.6%) occurred rapidly and all shrimp were dead within 3 hrs. At 15% all the shrimp were dead at 24 hrs. At concentrations greater than 15% the shrimp showed irritation when placed in the test solution and would jump completely out of the tank.
Kachemak Bay Pandalid shrimp (Pandalus hypsinotus)	Dames & Moore, 1978	static bioassay	drilling fluids	.025-20% by volume	96 hr LC50's values for pandalid shrimp ranged from 3.2 to 15% by volume. Total suspended solids at lowest LC50 equalled 14,000 mg/l.
White Shrimp (Panaeus setiferus)	Chesser & McKenzie, 1975	bioassay	drilling fluid additives	265-2100 ppm	The 96 hr TLM's for white shrimp were 265 ppm, 465 ppm, 2100 ppm for a modified Hemlock bark extract (*tannin*), *a chrome treated lignosulfonate* and an iron lignosulfonate, respectively. The chrome was present as trivalent chromium.
Oppossum Shrimp (Mysidopsis almyra) Grass Shrimp (Palaemonetes pugio) Polychaete Worm (Ophryotrocha labronica) Brown Shrimp (Pandeus aztecus)	Neff et al., 1980	bioassay	spud mud (spud) seawater chrome-lignosulfonate mud (CLS) mid-weight lignosulfonate mud (MWL) high-weight lignosulfonate mud (HWL)	9.2 to 17.4 lb/gal (1.09 to 2.07 kg/l	Aqueous extracts of the three used lignosulfonate drilling muds were similar to each other in their acute toxicity to the test species. In most but not all cases, the mid-weight lignosulfonate mud (MWL) was slightly more toxic than the high-weight lignosulfonate mud (HWL), and these two muds were somewhat more toxic than the seawater, chrome lignosulfonate mud. In most

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
					cases, larval and juvenile stages were more sensitive to the drilling mud preparations than adults. This was most pronounced for *Palaemonetes pugio*. It is concluded that the aqueous phase resulting from the addition of one part used lignosulfonate drilling mud to one-hundred parts seawater (e.g. 10,000 ppm mud added) may be toxic to sensitive species or life stages of marine animals.
Grass Shrimp (*Palaemonetes pugio*)	Conklin et al., 1980	bioassay	whole drilling muds and barite	whole drilling muds - 10 to 1000 ul/l (10 to 1000 ppm); barite - 100 to 500 ppm	Experiments with barite revealed that 80% of the control shrimp and 40% of the experimental shrimp (exposed to 100 and 500 ppm barite) survived the 30-day static exposure conditions. Depending on the type of particulate materials available in the medium at the time of molting, grass shrimp incorporated sand grains, barite or drilling mud particles into their statocysts, which are equilibruim receptors. Abnormal alterations were also observed in the posterior midgut. In testing acute toxicity to whole drilling muds, it was found that all mortalities were molt-related. In some instances shrimp were unable to successfully cast off the old exoskeleton and died during molting. In other cases, they molted successfully and died shortly thereafter.
CLAIM, MUSSELS, SCALLOPS					
Physiological Effects					
Mussel (*Modiolus modiolus*)	Dames & Moore, 1978	toxicity effects	drilling fluids	sublethal 1-3% by volume	Fourteen days exposure at 3% mud volume resulted in a reduction of feeding time, respiration, delayed byssus thread formation and possible abnormal uptake levels of heavy metals.
Sea Scallop (*Placopecten magellanicus*)	Liss et al., 1980	bioassay	drilling fluids	fluid suspensions of synthetic and used drilling muds	Introduction of drilling fluids into a cold marine environment will produce elevated levels of trace elements. While these elements will be associated principally with settling particles, there is likely to be a significant increase in their dissolved concentrations as well. Sea scallops were found to accumulate chromium and barium in their kidneys when exposed to synthetic muds. Chromium concentations were particularly elevated when compared to controls (chromium concentration rose from 1.74 ug/g of dry tissue to 4.35 ug/g; control concentrations dropped to 1.50 ug/g during the same period). Similar results were obtained for the used drilling muds although increases were not as marked. The taking up of Cr by sea scallops has been reported to be a function of the dissolved, rather than total, Cr loading.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Blue Mussel (*Mytilus edulis*)	Page et al., 1980	bioassay	spud mud light, medium and high density lignosulfonate muds	1:9 mud: seawater	At approximately normal seawater pH values (pH 8.3) data suggests that much of the chromium in a used mud may exist in a form having very low water solubility. At pH 2, the data shows that virtually all of the available chromium was released from the mud solids after 4 successive extractions. This result has possible implications for the bioavailability of mud-derived chromium from ingested mud in acidic digestive fluids of certain marine animals. At approximately equal concentrations of chromium in the seawater phase, Cr_3^+ exhibited the greatest bioavailability to blue mussels. This suggests that any toxic effects due to chromium arising from the release of used drilling muds into the open ocean may be mitigated by the decreased bioavailability of the form in which chromium is found in this material.
VARIOUS SPECIES					
Acute/Toxic Effects					
Mysids	Dames & Moore, 1978	static bioassay	drilling fluids	1-20% by volume	96 hr LC50's were 1% to 5% by volume for well mixed solutions and 10% to 15% in mixtures with no continuous mixing.
Copepod/Mysid	NALCO, 1976	24 hr and 48 hr static bioassay	whole mud and whole mud + paraformaldehyde (1.0 lb/barrel)		The mud and paraformaldehyde mixture (4-10 times the expected field concentrations for paraformaldehyde) resulted in complete mortality at all concentrations. Significant mortalities also occurred in concentrations of mud supernatent >5.7% for mysids and 10% for copepods.
Mysid Shrimp (*Mysidopsis bahia*) Oyster (*Crassostrea virginica*) Lugworm (*Arenicola cristata*)	Rubinstein and Rigby, 1980	bioassay	drilling fluid	10, 30 and 100 ppm	Mysids were not acutely affected. Of the 30 mysids exposed to each concentration, no mortality was observed in controls, one died at 10 ppm, and five died at 30 and 100 ppm drilling mud. After 10 days, three additional mysids died at 10 ppm, but no further mortality occurred at the higher concentrations. No oyster mortality occurred at any exposure concentration, however, oyster shell growth was significantly inhibited at concentrations of 30 and 100 ppm. Lugworms were severely affected by exposure to drilling mud. Seventy-five percent of the animals exposed to 100 ppm died during the test period, 64% mortality was observed at 30 ppm, and 33% mortality occurred at 10 ppm.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Arctic Marine Species	Tornberg et al., 1980	bioassays	drilling fluids	varied	The toxicity of drilling fluids varies widely between species. Fish were among the most sensitive organisms tested, and invertebrates included both sensitive and relatively resistant species. The 96-hour LC50 values for isopods, snails and polychaetes ranged from 60 - 70+% by volume of whole, used drilling fluids in seawater. Values for mysids ranged from 7 - 22%, amphipods 22 - 38%, broad whitefish 6 - 37%, fourhorn sculpin 4 - 35+%, Arctic cod 20 - 25% and saffron cod ranged from 17 - 30%. Variations in the toxicity for specific species appear to be attributable to variations in the physical/chemical characteristics of the drilling fluids used for the test. For a specific well, the toxicity appears to increase with increasing depth.
Alaskan Marine Organisms Pink Salmon (Oncorhynchus gorbuscha) Coonstripe shrimp (Pandalus hypsinotus) Mussel (Modiolus modiolus) Staghorn sculpin (Leptocottus armatus) Mysids (Neomysis integer) Amphipods (Eogammarus confervicolous) Isopods (Gnorimosphaeroma oregonensis)	Houghton et al., 1980	laboratory and In situ bioassay	drilling fluids for Lower Cook Inlet C.O.S.T. well	varied	Test solutions were prepared from drilling fluids taken directly from mud pits and mixed with ambient seawater. Toxicity of drilling fluids was generally low with 96-hour LC50 values ranging from 3,000 ppm (0.3 percent by volume of drill fluids to seawater) for pink salmon, to greater than 100,000 ppm, (10 percent) for shrimp. In situ toxicity studies on pink salmon fry, shrimp, and hermit crabs showed no mortalities that could be related to the discharge plume. Sublethal effects were only observed in mussels. Fourteen days of exposure at 3 percent mud produced a reduction of feeding and respiration (pumping) time, and delayed byssus thread formation.
Calanoid Copepod (Acartia tonsa) Atlantic Silverside (Menidia menidia) Marine algae (Skeletonema costatum)	EG & G Bionomics, 1976	bioassay	drilling fluids	varied	Acartia tonsa - 96 hr LC50 Saltwater gel mud - 100 ppm Lightly treated ferrochrome lignosulfonate-10,000 ppm seawater/freshwater mud Ferrochrome lignosulfonate freshwater mud-100 ppm Sewage plant effluent (extended aeration) - 2,200 ppm

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
					Menidia menidia 96-hour LC50 Saltwater gel mud - greater than 100,000 ppm Lightly treated ferrochrome lignosulfate - 48,500 ppm seawater/freshwater mud Ferrochrome lignosulfonate freshwater mud- greater than 100,000 ppm Skeletonema costatum 96-hour LC50 Saltwater gel mud - cell numbers of cultures exposed to 10 ppm increased slightly whereas cell numbers of cultures exposed to 1,800 ppm decreased by 84%. The toxicity of the mud appeared to decrease in the culture which was exposed to the next two higher concentrations (3,200 and 5,600 ppm) but increased again in all higher concentrations Lightly treated ferrochrome lignosulfonate seawater/freshwater mud - 96 hr LC50 was 3,700 ppm Ferrochrome lignosulfonate mud - no 96 hr LC50 could be determined
Alaskan Arctic Marine Species Amphipods (Onisimus sp.) Boekosimus sp.) Isopods (Saduria entomon) Polychaetes (Melaenis loveni) Snails (Nautica clausa, Neptunea sp. Buccinum sp.) Mysids (Mysis sp.) Fourhorn Sculpin (Myoxocephalus quadicornis) Broad Whitefish (Coregonus nasus) Arctic Cisco (Coregonus autumnalis) Arctic Cod (Boreogadus saida) Saffron Cod (Eleginus navaga)	Northern Technical Services, 1980	bioassays and histopathological examination	drilling fluids	varied	Species toxicity studies indicate the following values: Amphipods (Onisimus sp., Boeckosimus sp.) - 96-hour LC50 for amphipods exposed to varied drilling mud concentrations ranged from 22.1 percent to 38.1 percent. 96-hour LC50 values for reserve pit fluids were between 10 and 12 percent. Exposure to barite concentrations indicate that the 96-hour LC50 is greater than 84,000 ppm. Isopods (Saduria entomon) - Tests with XC-polymer/unical drilling fluids gave inconclusive results. In preliminary tests, concentrations of 50 percent resulted in total mortality. The 96-hour LC50 for exposures to CMC/Resinex/Tannathin/Gel drilling fluid were reported to be greater than 60 percent. Polychaetes (Melaenis loveni) - 96-hour LC50 value of greater than 70 percent was documented for polychaeted exposed to CMC/Resinex/Tannathin drilling fluid. Snails (Nautica clausa, Neptunea sp., Buccinum sp.) 96-hour LC50 was greater than the highest concentration tested (70 percent) for the three species. From mortality data and observations of behavior Buccinum sp. is more sensitive to drilling fluids than are Nautica clausa and Neptunea sp.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
					Mysids (*Mysis* sp.) - 96-hour LC50 for CMC/Gel/Resinex were between 6 and 7.3 percent. The 96-hour LC50 value for aerated and unaerated exposures to CMC/Gel were 12 percent and less than 4 percent respectively. XC- Polymer drilling fluid 96-hour LC50 values ranged between 5 and 17 percent. Tests with lignosulfonate gave an LC50 value estimated to be between 3,300 and 10,000 ppm. Fourhorn Sculpin (*Myoxocephalus quadicornis*) - 96-hour LC50 values for CMC/Resinex/Gel ranged between 4 and 7 percent. Stress was apparent in surviving individuals which were observed gasping at the surface of their tanks. LC50 values for XC-Polymer mud concentrations were inconclusive, but appeared to be greater than 20 percent. CMC/Gel studies using aerated and unaerated test containers resulted in 96-hour LC50 values of greater than 12 percent and 3.2 percent respectively. 96-hour LC50 values for lignosulfonates were between 1,000 and 6,000 ppm. Broad Whitefish (*Coregonus nasus*) - 96-hour values were derived for various age classes. Values ranged between 6.4 and 37 percent. Tests with lignosulfonate drilling fluids resulted in a high toxic value between 0 and 10 percent. Arctic Cisco (*Coregonus autumnalis*) Tests with XC-Polymer drilling fluids were inconclusive, 96-hour LC50 values for lignosulfonate drilling fluids were calculated to be 40 percent. Arctic Cod (*Boreogadus saida*) - The toxicities of XC-Polymer drilling fluid and lignosulfonate drilling fluid are similar. The 96-hour LC50 values ranged between 20 and 25 percent Saffron Cod (*Eleginus navaga*) - 96-hour LC50 values for saffron cod in CMC/Gel drilling fluid were between 17 and 30 percent. Histopathological examinations of fourhorn sculpin, broad whitefish, Arctic cisco, and Arctic cod show physiological damage may result from exposure to various drilling fluids (see Table 9). Analysis of the data also indicates that a relationship exists between the type of drilling mud used, the depth of the well and the measured acute toxicity (see Table 10).

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Physiological Effects					
Chironomid (*Chironomus tentans*)	Didiuk & Wright, 1975	physiological	waste drilling fluids on sediment surface	1, 3, 7 mm layers	Populations of Chronomid larvae treated with 1 mm, 3 mm, and 7 mm layers of drilling waste achieved only 65%, 47% and 12% emergence respectively, with peak emergence occurring 2, 23 and 25 days respectively after mud addition. Controls achieved 84% emergence with peak emergence occurring on the 16th day. Organisms from contaminated substrates were smaller in size. Muds appeared to interfere with feeding mechanisms.
Various Species of Marine Invertebrates	Gerber et al., 1980	bioassay	-spud mud -high, medium and light density lignosulfonate muds -seawater lignosulfonate mud	1-100% mud suspension dilutions	Cold water marine organisms exhibited low or no mortalities when exposed to various preparations of used drilling muds. Whole muds were slightly more toxic than mud aqueous fractions to most organisms but especially to deposit feeding organisms. Larvae were more sensitive than adults. Long term effects in mussels were reflected by reduced growth rates.
HABITATS					
Bottom Sediment	Grahl-Nielson et al., 1980	chemical analysis	drill cuttings	unknown	Sediment samples from an area surrounding a drilling platform in the North Sea were analyzed for hydrocarbon content. An approximate amount of 1,250 m^3 drill cuttings had been discharged previous to the sampling. Hydrocarbons resulting from these discharges were found in sediment over an area of 5 square kilometers. The detected amounts ranged from more than one thousand milligrams total hydrocarbons per kilogram of wet sediment (parts per million) in the vicinity of the platform down to less than 10 mg/kg. The drilling mud was of an oil-based nature and drill cuttings had been washed with diesel oil.
Bottom Sediment	Gettleson and Laird, 1980	chemical analysis	drilling fluid discharge	unknown	The distance that barium is dispersed as well as its benthic concentration appears to be dependent on at least three factors: 1) the types and quantities of drilling fluids discharged, 2) the hydrographic conditions at the time of discharges, and 3) the height above the bottom that the discharges are made. Barium analyses indicate that drilling fluids can be detected at least 1,000 meters, and possibly further, from both shunted and unshunted wells. In all cases the 100 meter station had a greater amount of barium deposited than did the drillsite (0 meters). This suggests that currents must carry even shunted muds at least some distance from the shunt pipe.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Estuarine Macrobenthic Communities	Tagatz et al., 1980	bioassay	varied	varied	Effect of Whole Mud and Barite: In the study, animal abundance was affected by whole mud and barite. In both studies, annelids (Armandia spp.) were found to be the most sensitive organisms with significantly fewer individuals in all contaminated aquaria than in control aquaria. In the mud study, numbers of the coelenterate Aiptasia pallida, were significantly reduced by all concentrations of mud. Numbers of molluscs were not significantly affected by mud-sand mixtures or by mud cover, and numbers of arthropods were significantly reduced only by mud cover. In the barite study, molluscs were fewer, however, numbers of chordates and arthropods were not significantly affected by the presence of drilling muds. Effects of Biocides: Abundance of animals was significantly decreased by the chlorophenol type biocides. Molluscs were found to be particularly susceptible to chlorophenol.
Terrestrial Vegetation (Alberta, Canada)	Younkin and Johnson, 1980	bioassay and observation	Drilling fluids; KCl/water/polymer dispersed water/gel flocculated water/gel	varied	Fluid from KCl/water/polymer drilling systems contained high organic carbon content and the highest salt content of all fluid types tested. Discharges of KCl fluids resulted in significant reductions in living native plant cover (5 to 30%) and in reed canary grass germination (75 to 80%) and productivity (37 to 60%). The salt component (at 34,000 ppm) of the sample fluids was identified as the most damaging to plant health and soil chemistry. The diesel fuel (at 4,500 ppm) had a slight effect while the lignosulfonate (at 165 ppm) and polymer (at 67,000 ppm) components had little effect on plant growth and vigor or soil chemistry.
Swiss Chard (*Beta vulgaris*) Ryegrass (*Lolium perenne*)	Nelson et al., 1980	bioassay	water-base drilling fluids	2.21 g/cm3 (18.4 lbs/gal)	Addition of high amounts of drilling fluids to fertile soils resulted in plant yield reduction. The mud components which reduced yields may have been soluble salts, Na+ ions, and/or heavy metals. Application of moderate rates of drilling muds prepared from relatively pure barites did not reduce yields. Cadmium, zinc, copper and lead present in drilling fluids were in part, available for plant uptake. The uptake of these metals was directly related to the concentration of the metal in the drilling fluid mixture. Mercury which was present in drilling fluid was not available for plant uptake.

Table 9 Histopathological examination of selected fish surviving 96-hour exposure to drilling fluids.*

Organisms	Drilling Fluid Concentration (% by volume)	Test	Comments
Fourhorn sculpins	0	108	Severe myositis was noted in the body wall of this fish. No other lesions were apparent. Recognizable microorganisms were not seen in association with the muscle inflammation.
Fourhorn sculpins	0	108	No visible lesions were present.
Fourhorn sculpins	25	108	No lesions were observed.
Fourhorn sculpins	25	108	With the exception of intestinal parasites no lesions were noted.
Fourhorn sculpins	25	108	Focal enteritis was the only observed alteration.
Broad whitefish	0	109	The only lesions observed were the presence of focal inflammation of the gills, the accumulation of proteinaceous fluid in Bowman's space of some glomeruli and in the lumens of some renal collecting tubules.
Broad whitefish	0	109	Focal inflammation and the presence of an aneurysm were seen in the gills. No other lesions were noted.
Broad whitefish	0	109	The only lesion observed was the presence of focal inflammation of the gills.
Broad whitefish	7.7	109	No lesions were noted.
Arctic cisco	0	113	Few hematopoietic cells were noted within the renal parencyma, but the kidneys were otherwise as expected. With the exception of mild hepatic hyperemia no other lesions were observed.
Arctic cisco	0	113	Little hematopoietic tissue was present within the renal parenchyma and multiple foci of mineralization were noted. In addition some glomeruli contained proteinaceous exudate within Bowman's space monogenetic trematodes were present in the gills.
Arctic cisco	8	113	Very few hematopoietic cells were present within the renal parenchyma and multiple foci of mineralization were present. No other lesions were noted.
Arctic cisco	12	113	The submitted tissues were normal except for the kidney which contained focal accumulation of proteinaceous fluid within Bowman's space of the glomerulus.
Arctic cisco	12	113	The intestinal mucosa was severly damaged and focally absent, and numerous bacteria were noted within the lumen of the intestine. Since no inflammatory reaction was present these changes appeared to be autolytic. Focal branchial hyperplasia and clubbing of lamellae tips were noted along with a leucocytic infiltrate at the bases of some lamellae. These changes may have been induced by the monogentic trematodes parasitising the gills.
Arctic cod	0	133	Numerous systematic degenerative changes were noted which resembled post mortem autolysis. In addition, the animal had severe, diffuse fatty degeneration of the liver.

* From: Northern Technical Services, 1980.

Table 10 Relationships of the type of drilling fluid and well depth to the acute toxicity of selected marine organisms.*

DRILLING FLUID	WELL DEPTH (m)	TEST ORGANISM	96-Hour LC50 VALUES (%)
CMC/Gel	1803	Eleginus navaga	17.0 - 30.0
CMC/Gel	1807	Mysis sp.	21.5
CMC/Gel	2780	Coregonus nasus	>20.0
CMC/Gel	2786	Myoxocephalus quadricornis	>12.0
XC-Polymer	2778	Coregonus nasus	33.0 - 37.0
XC-Polymer	3057	Boreogadus saida	>25.0
XC-Polymer	3064	Mysis sp.	16.1
XC-Polymer	3064	Myoxocephalus quadricornis	21.5
XC-Polymer	3319	Coregonus nasus	6.4
XC-Polymer	3319	Myoxocephalus quadricornis	>20.0
XC-Polymer	3323	Coregonus nasus	10.0
XC-Polymer	3324	Mysis sp.	26.0 - 40.0
XC-Polymer	3646	Mysis sp.	5.0 - 10.0
XC-Polymer	3646	Myoxocephalus quadricornis	5.0 - 10.0
XC-Polymer	3786	Onisimus sp., Boeckosimus sp.	38.1
XC-Polymer	3938	Onisimus sp., Boeckosimus sp.	28.0
XC-Polymer	4029	Onisimus sp., Boeckosimus sp.	27.8
XC-Polymer	4175	Onisimus sp., Boeckosimus sp.	22.1 - 24.1
CMC/Gel/Resinex	2786	Myoxocephalus quadricornis	5.0 - 6.0
CMC/Gel/Resinex	2786	Mysis sp.	>6.0
CMC/Gel/Resinex	3466	Mysis sp.	7.3
CMC/Gel/Resinex	3466	Myoxocephalus quadricornis	5.0 - 7.0

*From: Northern Technical Services, 1980.

Sensitivity of Areas and Recommended Mitigative Measures

Areas in the northern Bering Sea and Norton Sound were ranked as having a low, moderate, or high sensitivity to the impacts of drilling muds and cuttings discharge (see Map C). These designations were based on existing data, and were made after evaluating the following criteria:

1. The sensitivity of each fish and wildlife species or habitat to the effects of drilling muds and cuttings discharge.

2. The degree of sensitivity to drilling muds and cuttings discharge exhibited by each species during the various stages of its life history.

3. The time of year that these critical life history stages occur and the period during which each species would be most affected.

4. The location of habitats where critical life history stages occur.

5. The productivity of the habitat.

6. The uniqueness of the habitat.

7. The species population numbers and relative importance of the population.

8. The physical characteristics of receiving waters.

9. The degree to which the impacts of drilling muds and cuttings discharge can be mitigated.

Specific considerations and assumptions that were made during ranking are as follows:

1. Because toxic components of drilling muds can build up in shallow water areas with little dilution or dispersion processes, high sensitivity designations have been assigned to all nearshore regions seaward to the 30 ft. bathymetric contour line.

2. Based on oceanographic data which suggests circulation is sluggish in eastern Norton Sound, moderate sensitivity designations have been assigned to include all marine areas east of a line stretching from Rocky Point to Stuart Island.

3. Productive habitats such as eelgrass and *Fucus* kelp beds, wetlands, tideflats, and lagoons have been assigned a high impact value based upon their discrete characteristics and demonstrated importance to a variety of species. Additionally, any mud and cuttings discharges in these areas would result in a direct physical loss of habitat.

4. Although benthic species such as king crab, clams, starfish, etc., could be affected by discharges of drilling muds and

cuttings, they occur over such large areas that localized disturbances resulting from such discharges are unlikely to cause significant damage to either those species or their associated habitat. Subsistence harvests of these species, particularly king crab, remain vulnerable.

5. Based upon their respective vulnerability to toxicants, and their nearshore habitat requirements, Pacific herring and juvenile Pacific salmon have been assigned a high vulnerability rating to drilling muds and cuttings discharges.

Sensitivity Designations and Mitigative Measures

LOW SENSITIVITY AREAS

The designation of low sensitivity applies to areas where the impacts of drilling muds and cuttings discharge would be less adverse than in moderate or high sensitivity areas. Low sensitivity areas include: 1) marine areas with strong currents to adequately disperse and dilute muds and cuttings; and/or 2) areas with low numbers of sensitive species or habitats.

Drilling muds and cuttings may be discharged in low sensitivity areas in compliance with existing State and Federal water quality regulations.

MODERATE SENSITIVITY AREAS

Areas of moderate sensitivity are defined as those areas where the adverse impacts associated with the discharge of drilling muds and cuttings can be prevented, minimized, or ameliorated. Species or habitats which are present in these areas could be moderately affected by these discharges. Areas included in this category are:

1. Areas of sluggish circulation
2. Shorefast ice zone
3. Area of first open water in spring
4. Herring nearshore feeding and rearing areas
5. Capelin spawning and possible spawning areas
6. Nearshore rearing areas for juvenile fish (other than salmon)
7. Salmon nearshore migration areas
8. Arctic char and sand lance concentrations
9. Waterfowl and shorebird nesting and molting areas including; waterfowl major staging areas and important staging areas; emperor geese molting and staging areas; snow geese staging areas; shorebird fall staging areas and important habitats
10. Subsistence king crab harvest areas and subsistence freshwater mussel areas

Drilling muds and cuttings discharges should be conducted according to existing environmental regulations. Additional measures to mitigate the impacts of drilling muds and cuttings on moderate sensitivity areas include:

1. Wherever possible, drilling muds should be retained and used for drilling other wells.

2. Drilling muds should not be discharged into any nearshore area seaward to the 30 ft. bathymetric contour line, or any body of freshwater, including lakes, streams, or rivers.

3. If artificial islands are used to develop oil reserves in the northern Bering Sea-Norton Sound region, clean drill cuttings can be used as a material source to supplement gravel in island construction.

4. Drilling muds and clean drill cuttings should be discharged near the ocean bottom rather than near the surface in order to decrease the areal extent of outfall and to prevent stratification of toxic components within the water column.

5. Mud discharge rates should not exceed a maximum of 50 bbl per hour, in order to limit toxic concentrations of drilling muds to a small area near the outfall.

6. Muds should not be discharged at low tide or slack water when tidal flushing and dilution is at a minimum.

7. Drilling muds should be diluted prior to discharge. The minimum dilution factor should be 25 parts receiving water to 1 part drilling fluid.

8. Muds containing high levels (as determined by Environmental Protection Agency or Department of Environmental Conservation water quality regulations) of hydrocarbons, surfactants,

bactericides, detergents, trivalent chromium salts, carcinogenic compounds and other toxic additives should not be discharged into the aquatic environment. Instead, these muds should be hauled ashore and disposed of at an approved upland site, pumped down the well bore, or disposed of in some other environmentally acceptable manner.

9. During winter drilling in the shorefast ice zone, drilling muds should be dispersed on the ice surface rather than under the ice in poorly mixed subsurface waters where toxic build up may occur.

10. Clean drill cuttings may be discharged without restriction, except in areas which are important for the rearing of juvenile marine species, such as larval king crab; or in areas where such discharges will result in a direct physical loss of productive habitat, such as _Fucus_ kelp and eelgrass beds, wetlands, tideflats, or estuaries. The presence or absence of juvenile marine species and the relative productivity of an area should be determined during benthic and engineering surveys conducted prior to rig placement.

11. Heavy metal accumulations in sediment and animal tissues near production platforms with multiple wells, should be monitored to insure that no toxic build up occurs.

HIGH SENSITIVITY AREAS

Areas of high sensitivity are defined as those habitats where the impacts of drilling muds and cuttings discharge would be extremely adverse to fish and wildlife resources. Because of poor circulation, the nearshore area seaward to the 30 ft. bathymetric contour line would be included in this designation.

High sensitivity areas include:

1. Nearshore areas seaward to the 30 ft. bathymetric contour line
2. Eelgrass beds
3. *Fucus* kelp beds
4. Wetlands, tideflats and estuaries
5. Herring spawning, possible spawning, and wintering areas
6. Salmon streams and juvenile nearshore feeding and rearing areas
7. Sheefish and whitefish streams
8. Subsistence clam harvest areas
9. Commercial and subsistence herring harvest areas

Drilling muds should not be discharged into high sensitivity areas. Drilling sites and mud disposal areas should be designed and located so as to prevent drilling muds from being carried or leached into high sensitivity areas. The discharge of clean drill cuttings may be approved on a site specific basis.

TABLE 11: MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND SPECIES, HABITATS OR HARVEST ACTIVITIES ARE MOST SENSITIVE TO DRILLING MUDS AND CUTTINGS.

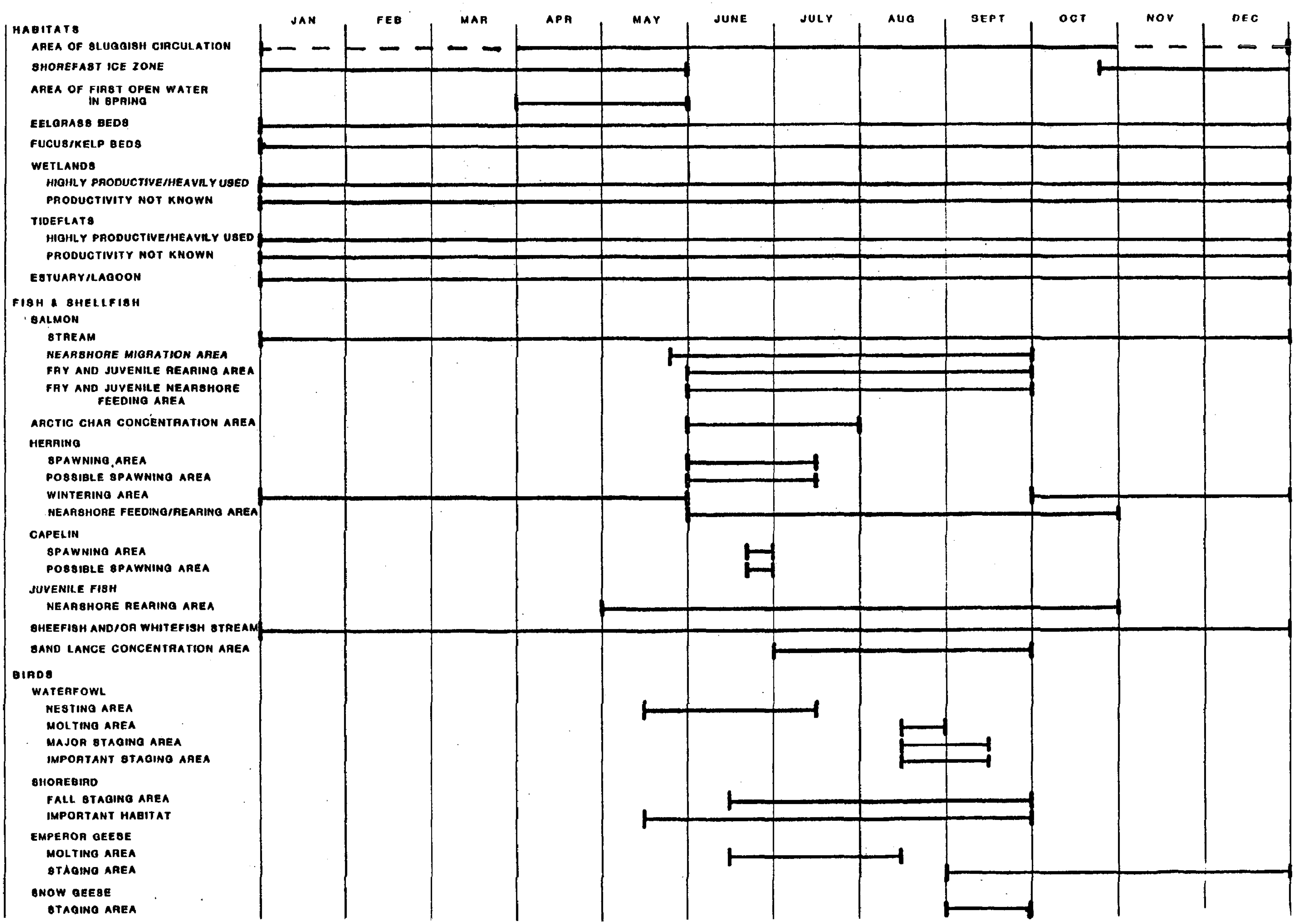
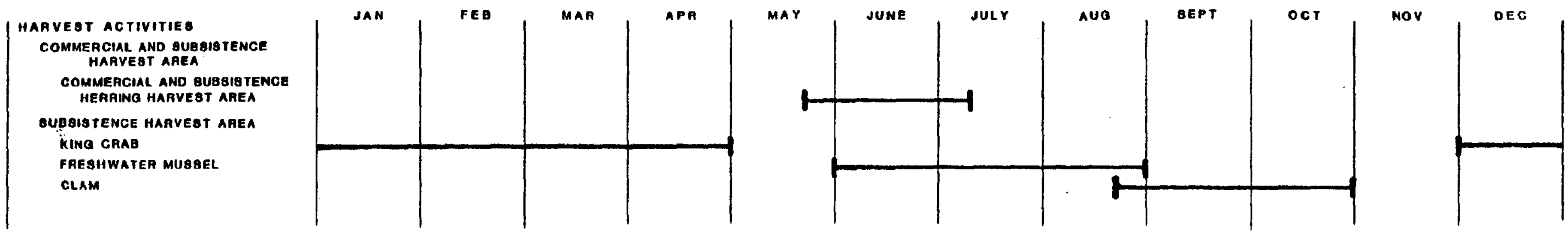


TABLE 11 : (CONT.)

MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND SPECIES, HABITATS OR HARVEST ACTIVITIES ARE MOST SENSITIVE TO DRILLING MUDS AND CUTTINGS.



D

OIL POLLUTION

OIL POLLUTION

Sources and Biological Effects

Sources

One of the major issues concerning offshore oil development is the possibility of oil pollution and the subsequent damage that may be inflicted upon sensitive fish and wildlife populations and their associated habitat. Oil pollution may occur under a variety of situations, and can be classified as being either acute or chronic depending upon its rate of introduction into the marine environment.

Acute oil pollution is that which results from a single infusion of oil into surrounding waters, generally by accident (NAS, 1975). Spills of this nature may occur during exploration and development drilling, production, transportation of oil, or oil processing. Acute oil pollution may also result from various support activities associated with offshore oil development such as fuel storage areas, refueling stations, pipelines and support bases (see Tables 12 through 20). In Alaska, statistics compiled for the 5 year period 1973-1977 show that the majority (55%) of oil spills (greater than 1,000 gallons) occurred as a direct result of transportation, handling, or storage of oil. Spills from production activities were additionally responsible for approximately 3% of the total volume spilled, while incidental spills (fishing vessels, aircraft, natural sources, etc.) accounted for the remaining fraction (42%).

TABLE 12

BUDGET OF PETROLEUM HYDROCARBONS INTRODUCED

INTO THE OCEANS (NAS, 1975)

	Input Rate (million metric tons)		
Source	Best Estimate	Probable Range	Reference
Natural seeps	0.6	0.2-1.0	Wilson et al. (1973)
Offshore Production	0.08	0.08-0.15	
Transportation			
Lot* Tankers	0.31	0.15-1.0	
Non-Lot* Tankers	0.77	0.65-1.0	
Dry docking	0.25	0.2-0.3	
Terminal Operations	0.003	0.0015-0.005	
Bilges Bunkering	0.5	0.4-0.7	
Tanker Accidents	0.2	0.12-0.25	
Non Tanker Accidents	0.1	0.02-0.15	
Coastal Refineries	0.2	0.02-0.3	Brummage (1973)
Atmosphere	0.6	0.4-0.8	Feuerstein (1973)
Coastal Municipal Wastes	0.3	-	Storrs (1973)
Coastal Non Refining			
Industrial Wastes	0.3	-	Storrs (1973)
Urban Runoff	0.3	0.1-0.5	Storrs (1973),Hallhagen (1973)
River Runoff	1.6	-	" "
TOTAL	6.113		

*Lot: Load on top.

TABLE 13

1973 ALASKAN MARINE OIL SPILLS $\geq$ 1,000 GALLONS

Material	Quantity (gallons)	Source	Cause
Light Diesel	196,182	Tankship 10,000-19,999 gross tons	Hull rupture or leak
Unidentified Heavy Oil	5,000	Onshore industrial plant or processing facility	Tank rupture or leak
Heavy Diesel	2,500	Onshore industrial plant or processing facility	Intentional discharge
Light Diesel	1,500	Onshore Non-transportation-related facility	Valve failure
Light Diesel	8,000	Miscellaneous	Pipe rupture or leak
Light Diesel	3,700	Other vessel	Equipment failure
Light Diesel	7,980	Tugboat or towboat	Tank rupture or leak
Other Oil	4,200	Onshore fueling	Intentional discharge
Light Diesel	1,500	Fishing vessel	Tank rupture or leak
Light Diesel	6,500	Other vessel	Structural failure
Light Diesel	4,500	Tank barge 1,000-9,999 gross tons	Tank rupture or leak
Light Diesel	22,500	Miscellaneous	Pipe rupture or leak
Natural Occurrence	9,200	Natural source	Natural phenomenon
Light Diesel	3,800	Miscellaneous	Tank overflow
Total	277,062 gallons		

Largest single oil spill: 196,182 gallons
Average quantity spilled: 19,790 gallons
Average quantity spilled excluding largest spill: 6,222 gallons

All 1973 Alaskan Marine Oil Spills (all quantities):

Number: 133
Total quantity: 281,506 gallons
Average quantity per spill: 2,117 gallons
Number of fishing vessel oil spills: 36
Average quantity per fishing vessel oil spill: 51 gallons

Source: United States Coast Guard Pollution Incident Reporting System data.

From: Terry et al., 1980. Alaska OCS Socioeconomic Studies Program-Technical Report #51.

TABLE 14

1974 ALASKAN MARINE OIL SPILLS $\geq$ 1,000 GALLONS

Material	Quantity	Source	Cause
Light Diesel	19,000	Land transportation facility	Personnel error
Light Diesel	6,000	Tugboat or towboat	Hull rupture or leak
Jet Fuel	5,000	Miscellaneous	Equipment failure
Light Diesel	5,200	Other vessel	Tank rupture or leak
Light Diesel	40,000	Onshore non-transportation-related facility	Pipe rupture or leak
Light Diesel	33,000	Onshore non-transportation-related facility	Pipe rupture or leak
Light Crude Oil	1,050	Offshore bulk cargo transfer	Improper equipment handling or operation
Light Diesel	7,000	Miscellaneous	Structural failure
Light Diesel	10,000	Onshore fueling	Tank rupture or leak
Light Diesel	2,500	Land transportation facility	Valve failure
Light Diesel	33,000	Miscellaneous	Tank overflow
Gasoline	5,800	Unknown type of source	Unknown cause
Light Diesel	1,200	Onshore non-transportation-related facility	Pipe rupture or leak
Light Diesel	3,200	Onshore bulk cargo transfer	Transportation pipeline rupture or leak
Light Diesel	1,600	Highway vehicle liquid bulk carrier	Natural or chronic phenomenon
Total	173,550 gallons		

Largest single oil spill: 40,000 gals. Average quantity spilled: 11,570 gals.
Average quantity spilled excluding largest spill: 9,539 gals.

All 1974 Alaskan Marine Oil spills (all quantities):

Number: 153 Total quantity: 181,409 gals. Average quantity per spill: 1,186 gals.
Number of fishing vessel oil spills: 24
Average quantity per fishing vessel oil spill: 71 gals.

Source: United States Coast Guard Pollution Incident Reporting System data.

From: Terry et al., 1980. Alaska OCS Socioeconomic Studies Program-Technical Report #51.

TABLE 15

1975 ALASKAN MARINE OIL SPILLS $\geq$ 1,000 GALLONS

Material	Quantity	Source	Cause
Light Diesel	1,100	Highway vehicle liquid bulk carrier	Natural or chronic phenomenon
Heavy Diesel	5,000	Fishing vessel	Hull rupture or leak
Light Diesel	1,000	Miscellaneous	Unknown causes
Jet Fuel	1,500	Onshore bulk storage facility	Equipment failure
Light Diesel	2,000	Highway vehicle liquid bulk carrier	Personnel error
Light Diesel	65,000	Onshore pipeline	Pipeline rupture or leak
Gasoline	300,000	Onshore fueling	Tank rupture or leak
Total	375,600 gallons		

Largest single oil spill: 300,000 gallons
Average quantity spilled: 53,657 gallons
Average quantity spilled excluding largest spill: 12,600 gallons

All 1975 Alaskan Marine Oil Spills (all quantities):

Number: 136
Total quantity: 380,275 gals.
Average quantity per spill: 2,796 gals.
Number of fishing vessel oil spills: 30
Average quantity per fishing vessel oil spill: 201 gals.

Source: United States Coast Guard Pollution Incident Reporting System data.

From: Terry et al., 1980. Alaska OCS Socioeconomic Studies Program-Technical Report #51.

TABLES 16

1976 ALASKAN MARINE OIL SPILLS ≥ 1,000 GALLONS

Material	Quantity	Source	Cause
Heavy Diesel	40,000	Onshore bulk storage facility	Transportation pipeline rupture or leak
Jet Fuel	9,000	Rail vehicle liquid bulk	Railroad accident
Light Crude Oil	2,000	Onshore oil or gas production facility	Hose rupture or leak
Gasoline	1,500	Aircraft	Aircraft accident
Mixture of Two or More Petroleum Products	2,000	Offshore production facility	Equipment failure
Light Diesel	2,000	Onshore bulk storage facility	Tank rupture or leak
Light Diesel	1,000	Fishing vessel	Tank rupture or leak
Light Diesel	1,000	Railway fueling facility	Improper equipment handling or operation
Jet Fuel	395,670	Tankship 10,000-19,999 gross tons	Hull rupture or leak
Light Diesel	4,000	Highway vehicle liquid bulk	Highway accident
Light Diesel	9,000	Onshore non-transportation-related facility	Improper equipment handling or operation
Total	467,170		

Largest single oil spill: 395,670 gals. Average quantity spilled: 42,470 gals.
Average quantity spilled excluding largest spill: 7,150 gals.

All 1976 Alaskan Marine Oil Spills (all quantities):

Number: 234 Total Quantity: 475,820 gals. Average Quantity per Spill: 2,033 gals
Number of fishing vessel oil spills: 48
Average quantity per fishing vessel oil spill: 75 gals.

Source: United States Coast Guard Pollution Incident Reporting System data.

From: Terry et al., 1980. Alaska OCS Socioeconomic Studies Program-Technical Report #51.

TABLE 17

1977 ALASKAN MARINE OIL SPILLS ≥ 1,000 GALLONS

Material	Quantity	Source	Cause
Jet Fuel	10,192	Onshore bulk storage	Pipe rupture or leak
Light Diesel	72,280	Fishing vessel	Hull rupture or leak
Light Diesel	1,000	Fishing vessel	Hull rupture or leak
Heavy Diesel	8,000	Fishing vessel	Hull rupture or leak
Light Diesel	1,000	Onshore bulk cargo transfer	Personnel error
Light Diesel	10,000	Onshore industrial plant or processing facility	Highway accident
Light Diesel	8,000	Fishing vessel	Hull rupture or leak
Light Diesel	2,600	Onshore non-transportation-related facility	Tank overflow
Unidentified light oil	1,600	Onshore bulk storage facility	Pipe rupture or leak
Total	114,672		

Largest single oil spill: 72,280 gals.
Average quantity spilled: 12,741 gals.

Average quantity spilled excluding largest spill: 5,299 gals.

All 1977 Alaskan Marine Oil Spills (all quantities):

Number: 229
Total quantity: 123,633 gals.
Average quantity per spill: 540 gals.
Number of fishing vessel oil spills: 56
Average quantity per fishing vessel spill: 1,600 gals.

Source: United States Coast Guard Pollution Incident Reporting System data.

From: Terry et al., 1980. Alaska OCS Socioeconomic Studies Program-Technical Report #51.

TABLE 18

NUMBER OF ALASKA MARINE OIL SPILLS ≥ 1,000 GALLONS, BY MATERIAL SPILLED 1973-1977

	Number of Incidents				
	1973	1974	1975	1976	1977
Material Spilled					
Light Crude Oil		1		1	
Gasoline		1	1	1	
Jet Fuel		1	1	2	1
Light Diesel Fuel	10	12	4	5	6
Heavy Diesel Fuel	1		1	1	1
Mixture of Two or More Petroleum Products				1	
Unidentified Light Oil					1
Unidentified Heavy Oil	1				
Other Oil	1				
Natural Occurrence	1				
Total	14	15	7	11	9

Source: United States Coast Guard Pollution Incident Reporting System data.

From: Terry et al., 1980. Alaska OCS Socioeconomic Studies Program-Technical Report #51.

TABLE 19

NUMBER OF ALASKAN MARINE OIL SPILLS ≥ 1,000 GALLONS, BY CAUSE 1973-1977

Cause of Oil Spill	1973	1974	1975	1976	1977
Structural Failure or Loss					
Hull Rupture or Leak	1	1	1	1	4
Tank Rupture or Leak	4	2	1	2	
Transportation Pipeline Rupture or Leak		1		1	
Other Structural Failure	1	1			
Equipment Failure					
Pipe Rupture or Leak	2	3	1		2
Hose Rupture or Leak				1	
Valve Failure	1	1			
Other Equipment Failure	1	1	1	1	
Personnel Error (Unintentional Discharge)					
Tank Overflow	1	1			1
Improper Equipment Handling or Operation		1		2	
Other Personnel Error					
Intentional Discharge	2				
Other Transportation Casualty					
Railroad Accident				1	
Highway Accident				1	1
Aircraft Accident				1	
Natural or Chronic Phenomenon	1	1	1		
Unknown Causes		1	1		
Total	14	15	7	11	9

Source: United States Coast Guard Pollution Incident Reporting System data.

From: Terry et al., 1980. Alaska OCS Socioeconomic Studies Program-Technical Report #51.

TABLE 20

NUMBER OF ALASKAN MARINE OIL SPILLS ≥ 1,000 GALLONS
BY SOURCE OF SPILL 1973-1977

Source of Oil spill	1973	1974	1975	1976	1977
Other Vessel	2	1			
Tankship 10,000-19,999 gross tons	1			1	
Tank Barge 1,000-9,999 gross tons	1				
Tugboat or Towboat	1	1			
Fishing Vessel	1		1	1	4
Onshore Bulk Cargo Transfer		1			1
Onshore Fueling	1	1	1		
Offshore Bulk Cargo Transfer		1			
Rail Vehicle Liquid Bulk				1	
Highway Vehicle Liquid Bulk		1	2	1	
Aircraft				1	
Other Land Transportation Facility		2			
Railway Fueling Facility				1	
Onshore Pipeline			1		
Other Onshore Non-Transportation-Related Facility	1	3		1	1
Onshore Bulk Storage Facility		1		2	2
Onshore Industrial Plant or Processing Facility	2				1
Onshore Oil or Gas Production Facility				1	
Offshore Production Facility				1	
Miscellaneous - or Natural Source	4	3	1		
Unknown Type of Source		1			
Total	14	15	7	11	9

Source: United States Coast Guard Pollution Incident Reporting System data.

From: Terry et al., 1980. Alaska OCS Socioeconomic Studies Program-Technical Report #51.

Typically, the largest and potentially most damaging forms of acute oil spillage occur as a consequence of tanker accidents or oil well blowouts. Massive spills associated with the break-up of such supertankers as the Torrey Canyon and Amoco Cadiz, and blowouts such as the Santa Barbara spill or, more recently, the Ixtoc I well in the Gulf of Mexico, have the capacity to foul miles of coastline, inflict millions of dollars of damage, and produce extensive mortalities in marine and avian populations. Efforts to contain or control the flow of oil once accidents of this type occur are usually ineffectual, or may occur too late to prevent significant quantities of oil from escaping. The runaway Ixtoc I well which flowed out of control for 295 days and released an estimated 140 million gallons of oil into the marine environment is a case in point. A variety of measures were applied in an attempt to cap the well, but ultimately two relief wells had to be drilled before the flow of oil could be stemmed.

United States Geological Survey statistics as compiled by Danenberger (1980) show that 46 blowouts have occurred on the Outer Continental Shelf of the United States between 1971 and 1978. Thirty of the blowouts occurred during drilling operations, while the remaining 16 occurred during completion, production, and workover operations. Of the 46 blowouts recorded, only three resulted in significant quantities of oil (less than 1,000 barrels in combination) escaping into the marine environment. During the 8-year study period, 7,553 new wells were started and, on the average, one blowout occurred for every 250 wells drilled.

Chronic oil pollution is the discharge of hydrocarbons either continuously or sufficiently often such that aquatic biota does not have time to recover. Annually, chronic sources add more oil to the marine environment than do acute spills. In many cases the environment is often resilient or responsive enough to return to a stable state following a catastrophic event such as an acute oil spill, but a slow and steady degradation of the environment as is the case with chronic oil pollution, may present a more serious alteration (Dey and Damkaer, 1977; Michael, 1977; Armstrong et al., 1979). Sources of chronic hydrocarbon pollution may include discharge from platform deck drains, effluent (formation water) discharge from oil-water separators on production platforms, effluent from refinery and petrochemical plants, and discharge from vessels, tankers and ballast water treatment facilities.

Fates of Oil in Marine Environments

Oil may enter the marine environment through a variety of sources and in a variety of forms, therefore it is important to understand the processes that are involved in its ultimate distribution, physical configuration, and chemical constituency. Studies reveal that the effects of marine oil spills on marine ecosystems are directly related to the following factors: 1) type of oil spilled, 2) amount of oil spilled, 3) physiography of the spill area, 4) weather conditions at the time, 5) biota in the area, 6) season of the year, 7) previous exposure of the area to oil, 8) exposure to other pollutants, and 9) method of treatment of the spill (Clark and Terrel, 1978). The various permutations that may be derived from these nine parameters make each oil spill unique. However, most oil spills also exhibit uniform characteristics of behavior which arise as a result of their discharge into a marine environment. The following discussion on fates of oil in the marine environment is primarily taken from the Food and Agriculture Organization of the United Nations (FAO) report titled "Impact of Oil On the Marine Environment"; and is co-authored by an international group of expert organizations studying the scientific aspects of marine pollution (GESAMP, 1977).

Spreading - Typically, the first process to influence the fate and eventual impact of a spill is that of extension, or spreading of the oil product over the marine surface in the form of a thinning film. Gravitational effects initially control the rate of spreading, but as time increases and the oil layer thins, slick size becomes controlled by a surface tension-viscosity relationship which is independent of the spill volume. The area occupied by the slick will increase rapidly under the influence of both hydrostatic and surface forces until further enlargement is limited and offset by natural forces. It appears that even viscous crude oils will react in a similar manner, spreading rapidly into thin layers which then come under the influence of surface effects. Once a spill has thinned and surface forces begin to play an important role, the oil film is no longer continuous and uniform but rather becomes fragmented by wind and waves into patches and windrows.

Evaporation - Evaporation is the process by which low to medium molecular weight components with relatively low boiling points are volatized into the atmosphere. This process may occur up to several months after a spill, but generally is most intense during the first few hours to weeks. Riisgard (1979) estimated that as much as 50% of a light crude oil could evaporate within the first week following a spill. Evaporation can be an important means of preventing toxic components from initially entering a marine ecosystem, although some higher weight aromatics, which are thought to be involved in long-term toxicity, are less volatile and are practically unaffected by evaporation over long periods of time. Evaporation therefore selectively depletes the lower boiling components of the oil, increasing the specific gravity as the oil loses its volatile fraction. As specific gravity increases, the residual oil may become denser than sea water, increasing the possibility of sinking. This process then can contribute to the formation of thick residuals, oil sludges, and eventually, the possible formation of tar balls or tar mats.

Solution - Solution is the physical process by which low molecular weight hydrocarbons are lost by the oil to the water. The rate of this process is governed by wind, sea state, and the properties of the petroleum material itself (chemical composition, specific gravity, viscosity, pour point, surface tension etc.). Since the soluble fraction of most petroleum products consists mainly of medium weight aromatics, and this fraction contains the compounds known to be the most toxic, persistence of the soluble fraction is an important aspect to consider in determining the relative harmful effects of a petroleum product. Frankenfield (1973) investigated the weathering of No. 2 fuel oil, Bunker C residual oil, and Venezuelan crude oil under simulated natural conditions and found that after a weeks weathering, the dissolved fraction of the No. 2

fuel oil was approximately 3.5 times that found for the heavier oils. This contradicts the idea that light oils disappear almost entirely due to evaporation shortly after being introduced into the marine environment. The above evidence indicates that lighter oils more readily pass into solution within the water column than heavy oils, and that light oils may persist in the water column whereas heavy oils form surface slicks.

Emulsification - Rough seas tend to create emulsions of oil and water. This process may take two forms: oil-in water emulsions, where the sea is the continuous phase, or water-in-oil emulsions, where the stable floating emulsion contains about 30 to 80 percent water. Water-in-oil emulsions have been found to be stable for periods exceeding 100 days, and are thought to be the product of accumulated non-volatile residues, particularly asphaltenes, in crude oils. The formation of water-in-oil emulsions generally requires violent agitation at the air/sea interface and relatively thick oil films.

Oil-in-water emulsions may form as a result of stresses at the sea surface forcing oil into the water as small drops. This may occur naturally or through the use of dispersants. Emulsification of crude oil may also be promoted by surface-active materials produced during degradation of the oil by certain micro-organisms.

Sedimentation - The process of oil adsorbing to sediment particles is of particular relevance in the Norton Sound-Bering Strait region where immense sediment discharges from the Yukon River occur annually. Oil suspended in the water column could adhere to suspended sediment particles causing them to settle to the ocean bottom and eventually become trapped beneath successive layers of sediment. Very little oxidation would occur once hydrocarbons were buried in reducing sediments. With extremely cold marine sediments, the rate of degradation may be even slower than that which usually occurs (Percy and Mullin, 1975). The mechanisms by which sedimented oil may be resuspended and spread over wide areas, long after the original spill, are not well understood. However, various resedimentation and suspension processes which can occur include: current movement, storm surges, resuspension by pressure waves, or resuspension by organic reworking of surface sediments.

Chemical degradation - The nature of the chemical degradation process is not precisely known, but would appear to be largely the result of the photo-oxidation of hydrocarbons, with the result that oxidized compounds are more soluble in water than the original compounds. Perhaps the most notable effect is an increase in resin and asphaltene content.

Microbial degradation - As the residence time of oil on water increases, biological processes begin to operate and rapidly gain in significance. Over 90 species of micro-organisms (bacteria and fungi) capable of subsisting on petroleum, and therefore capable of degrading it by biological oxidation, have been identified. The extent of such degradation in the sea is dependent upon water temperature, and the presence of certain volatile fractions (naphtha and kerosene) in the spill, some components of which are bacteriocidal or bacteriostatic. When these fractions are removed the residues become more biodegradable than the crudes from which they originate. Atlas et al. (1980), studying microbial populations in arctic marine sediments found that biodegradation commenced only after several months exposure, and that there seemed to be a preference for straight chain alkanes over branched chain alkanes.

Oil and Ice Interactions

The preceding section described the various characteristics and eventual fate of oil released into a marine environment. The properties mentioned are typical in the sense that they are the most predictable aspects of a marine oil spill, and may occur to varying degrees regardless of the oil type involved. It should be realized, however, that these aspects of oil spill behavior are applicable only under circumstances in which ice is not present. When oil is introduced into a marine system containing ice, the oil can be expected to behave in a markedly different manner.

In the Norton Sound-Bering Strait region ice is normally present seven months of each year. Because of this, oil drilling operations must contend with the variable hazards associated with drilling in an environment where an inordinate degree of stress may be placed on fixed surface structures. The presence of moving ice will increase both the danger of an oil spill and the difficulty involved in cleaning it up. Should an accident occur during winter operations, oil behavior under ice will be significantly influenced by the type of ice with which it comes in contact.

Stringer and Weller (1980) have proposed a scale of behavior involving oil interactions within a variety of ice types. Their study defines oil/ice interactions as occurring on a micro-scale, where oil becomes incorporated within individual crystals of growing ice, up through the development of pancake ice; a meso-scale where characteristics of pack ice floe movement and ice ridging are the dominant influencing factors determining oil behavior; and a large scale where oil transport over great distances could occur.

Initially, when oil is introduced into an area where wind or wave action generates ice, mixing occurs with a slurry of small ice crystals and seawater, termed grease ice. The most important property of grease ice, as it relates to possible oil entrainment is the existence of a dead zone, or area of transition between liquid and solid behavior (Martin, 1980). Laboratory experiments indicate that most of the oil introduced into a grease ice system would end up on the ice surface beyond the dead zone, with some oil droplets circulating in the grease ice ahead of the dead zone (Martin, et al., 1978). In this manner oil might become directly incorporated within new growing ice as it forms. Further field observations also confirm that if oil were spilled in the various polynya zones of a freezing ice front, some of the oil would accumulate on the grease ice surface, some would accumulate in the local dead zones, and a smaller fraction would be emulsified into oil droplets by wave breaking. These droplets might then circulate around within both the grease ice and the ocean circulation at the ice front (Martin, 1980; Stringer and Weller, 1980).

As grease ice freezes further it develops into flat "pancake ice". Experiments with Prudhoe Bay crude oil have shown that approximately 25%

of the oil released beneath pancake ice can be pumped to the ice surface by the oscillating motion of the ice itself. The rest of the oil may be bound up as small droplets in grease ice under the pancakes (Martin, 1980).

A third type of micro-scale oil/ice interaction occurs when oil is released under stable, stationary first-year ice, as is typical of the shorefast ice zone that encircles the perimeter of Norton Sound. Various studies (NORCOR, 1975; Rosnegger, 1975; Hoult et al., 1975; Uzuner et al., 1979; Martin, 1979) have concerned themselves with the circumstances surrounding such an occurrence, and the processes involved are relatively well understood. The disposition of oil under solid ice cover is controlled primarily by three factors; the nature of the discharge, the condition of the ice, and the physical variables associated with the discharge of oil. Oil may be discharged beneath ice through the rupture of an underwater pipeline, an oil well blowout, natural oil seepage, or oil leakage from a ruptured vessel (Uzuner et al., 1979). In the case of a blowout, well head temperature, pressure, the quantity of gas and oil, water depth, and currents will all influence the plume and ultimately the disposition of the oil (NORCOR, 1975). Martin (1980), after conducting experiments in the Canadian Beaufort Sea, found that oil interactions beneath first year ice may be separated into three periods of characteristic behavior:

1.) November - February - When oil is first released under smooth first-year ice it collects in natural undulations beneath the ice, which are caused by snowdrift - induced insulation. These undulations have an amplitude of order 0.1 m and a length scale of order 10 m. Some oil also flows a short distance up into the ice through brine drainage channels.

2.) March - May - In the spring as the ice warms, top-to-bottom brine channels open up in the ice and the oil rises through these channels to the surface where it spreads laterally, both under the snow and within the first few porous centimeters of the ice surface. The oil on the surface then absorbs solar radiation through the snow, causing the snow above the oil to melt.

3). June - August - In the early part of the summer the trapped oil will continue to rise through the ice to the surface where melt ponds with oily surfaces then form. Because the sun heats the oil (which absorbs heat more rapidly than the reflective snow surface), and the winds blow the oil on the melt pond surfaces against the edges of the ponds, the oiled melt ponds grow both laterally and in depth faster than the unoiled ponds. As the ice continues to decay, much of the oil in a weathered form will flow back into the ocean either as runoff from the tops of the floes or by melting through the ice bottom.

In the sub-arctic Norton Sound-Bering Strait region, the time frame will be reduced, but the processes involved are likely to be the same.

Meso-scale oil and ice interactions which might occur in the northern Bering Sea include transport of oil along leads (including "lead pumping"), and oil incorporation in pressure ridges. Oil migrating into open leads will be compressed to greater film thicknesses, and longitudinal flow along the leads will occur from areas of thick oil films to unoiled portions of the leads. This process will continue until obstructions in the leads cause the oil to overflow onto the surrounding ice (Stringer and Weller, 1980). Since the ice is in continual motion, with leads progressively opening and closing, the oil could be pumped a considerable distance from the area originally contaminated (Logan et al., 1975).

When leads close completely the ice on either side of the lead may be deformed into pressure ridges. Before the lead closes, the bulk of the contained oil can be expected to spill over onto the surrounding ice. As the ridge then forms, the oiled ice will be broken up and incorporated into the ridge itself (Stringer and Weller, 1980). In this manner oil may become entrapped in the ice thereby effectively preventing any immediate cleanup, and allowing the oil to be reintroduced into the marine environment at a later date when the ice subsequently melts. Other meso-scale considerations involve the interaction of oil with obstructions under a solid ice cover. It has been found that small obstructions such as exist in many ice fields, and even large ridge keels will not obstruct the motion of a slick if current velocities are sufficient (15-25 cm/sec) to cause the slick to move under small-scale rough ice. However, the limited oceanographic information available indicates that under ice currents in Norton Sound are weak, and it is likely that deep pooling would occur instead if obstructions are close to the source of spilled oil. Even in the absence of obstructions, the oil equilibrium thickness (0.5 to 1.0 cm) is generally so great that large amounts of spilled oil may be contained in a relatively small area due to that mechanism alone (Stringer and Weller, 1980).

Large scale transport of oil in ice is a very real possibility in the Bering Sea. Pease (1979) analogizes ice generation and transport in the

Bering Sea to the mechanic operations of a "conveyor belt". Ice develops in the northern and coastal regions of the Bering Sea, subsequently advects in a south-southwesterly direction, melts along the southern margin of the ice pack, and is replaced by new incoming ice. Oil trapped within growing ice could therefore be transported and released several hundred miles away. In this manner, the Bering Sea ice pack is believed to replace itself eight times during the course of a winter. There is also evidence that while ice moves in a wind induced southward direction, oceanic currents move in a northerly direction. As a result, less buoyant weathered petroleum released from the ice could be transported back beneath the ice cover (Stringer and Weller, 1980).

The implications of oil capture and transport are significant when the physical aspects associated with such scenarios are considered. Oil trapped in ice does not weather substantially, instead it retains much of its original toxic components, which can then be later released as the ice disintegrates (NORCOR, 1975; Logan et al., 1975). Processes normally associated with weathering such as evaporation, dissolution and biodegradation may still occur, but will be extremely restricted. Similarly, degradation of oil trapped beneath the ice appears also to be limited (Atlas, 1977).

Oil can also directly affect ice characteristics. The thermal conductivity of most crude oils is roughly one fifteenth that of natural sea ice, therefore an oil lens situated beneath a sheet of ice may act as an insulator, causing a reduction in heat flux and a subsequent reduction in ice growth. This process is likely to occur on a short term basis, returning to a normal temperature gradient once the oil becomes encapsulated (NORCOR,1975). In the spring, higher ambient air temperatures and increased solar radiation will induce the formation of top-to-bottom brine channels which allow entrapped oil to migrate to the ice surface (NORCOR, 1975; Martin, 1979). Once on the surface, oil will saturate the snow cover, causing a reduction in albedo (reflectant property). This further accelerates the process of ice degeneration by increasing the absorption of solar radiation. Oiled areas are then likely to be free of ice one to three weeks in advance of the gross failure of the sheet (NORCOR, 1975).

Direct observations of oil and ice interactions have been recorded following the breakup of the oil tanker Kurdistan off the Cape Breton coast (C-Core, 1980). During this incident the Kurdistan, carrying a cargo of 29,000 tons of Bunker-C oil was significantly damaged by heavy ice and was forced to return to open water. The vessel subsequently broke apart and an estimated 7,000 tons of Bunker-C was lost. Initially, the oil with a pour point between 15°C and 20°C congealed rapidly in the cold water. One week later oil was reported in the pack ice in the form of long bands and streaks. Although the preliminary events leading to entrainment of the oil in the ice are unknown, during the period of observation, most processes tended toward a finer dispersion and dilution of the oil.

One of the primary dispersion processes was the grinding of oil in brash ice as a result of floe impact and differential movement. In the offshore pack, swell propagation caused a leisurely grinding motion which produced oil particles ranging from a few centimeters in diameter down to micron sizes. During extreme sea states, breaking waves resulted in churning chunks of ice which rapidly reduced oil blobs to a very fine dispersion with relatively uniform distribution. An additional aspect of the grinding process appeared to be a considerable incorporation of organic or mineral material into the oil itself. Samples collected some distance offshore contained "surprising" amounts of heavy mineral particles which were believed to have been picked up from floe surfaces.

A secondary process which also tended to reduce particle size occurred as a result of solar heating on snow/ice surfaces. The ice beneath blobs of oil would melt, causing the oil to be stretched and spread until surface tension effects intervened to produce micron sized oil particles. Individual particles showed no sign of strong adhesion to the ice, and in many cases became trapped as new ice formed over those particles which had became concentrated in melt pockets.

One unexpected result arising from chromatographic analysis of brash ice samples was the apparent tendency for certain light hydrocarbons to be preferentially enriched (retained). Enrichment of even numbered hydrocarbons (C14 - C20) was found to further occur in analyses of ice cores from floes and ice rubble drifts. The preferential retention of light fractions by sea ice could have significant effects on the epontic algal community in those areas where biological activity on decaying ice is an important part of the spring bloom (C-Core, 1980).

Spill Transport and Containment

There are a number of factors which are important in determining the degree of hazard which oil pollution in offshore areas poses for the biological resources in both the coastal and offshore zones. The major physical processes affecting the transport and areal dispersion of hydrocarbon pollutants during a summer spill are 1) net circulation, 2) surface spreading, 3) wind transport, 4) oscillatory tidal currents, and 5) mixing. Transport may differ significantly depending on whether the oil is in solution within the water column, or if it is spread over the water surface in the form of a slick. Oil in solution, or oil which has been mixed within the water column will be carried primarily with the currents. Surface oil slick transport is additionally affected by direct wind influence, surface spreading, and other surface processes.

Net Circulation - The effect of net circulation on oil slick transport is generally self-evident. In the absence of other modifying influences, an oil slick will simply be carried with the surface currents. However, this straight-forward transport mechanism is complicated by a number of additional variables, including a large variability in the "normal" net circulation itself. Alterations in the "normal" net surface circulation pattern are continually produced by variations in freshwater runoff, seasonal temperature changes, winds, periodic variations in tidal range, and other factors. These natural variations make it difficult to model or predict the path and eventual landfall of a spill with any degree of reliability.

Spreading - Surface spreading (in the absence of winds or currents) will greatly enlarge the area of a surface oil slick. Spreading results from the influence of gravity which causes a film of oil to thin and spread laterally. In areas where there is restricted circulation, such as a gyre in a bay, surface spreading alone would greatly increase the area of the bay which would be affected by the spill. The rate of spreading and the total area of spread over calm water will vary as a function of the composition and viscosity of the oil, the seawater and air temperature, and other factors. A representative calculation of oil spreading which excludes contributing physical processes (wind, waves, currents, and tides), indicates that a 65,000 barrel oil spill would, after 11 days, spread to a diameter of 18.2 kilometers (11.3 miles) (BLM, 1976).

Wind Transport - Wind-induced surface transport of oil is frequently the most influential variable. Wind will move a surface oil slick at 2.5-4.5% of the wind speed and at an angle of 0-45° to the right (in the northern hemisphere) of the wind direction (Kinney, 1976). The movement velocity most commonly accepted is 3% of the wind speed in a direction very close to that of the wind (BLM, 1976; Dames and Moore, 1976). The wind influence is, at least initially, superimposed upon the "normal" net circulation. Movement of the slick can then be represented as the vector sum of the surface current velocity and approximately 3% of the wind velocity (Dames & Moore, 1976). Strong winds will overide any surface current influences. The slick movement may take the form of a very near-surface "skim layer shear" in which the oil slick and a very near-surface layer of water slides over the underlying waters (Battelle Northwest, 1970); however, the surface wind stress is generally transmitted to the underlying waters and progressively alters the deeper surface water currents. As the wind alters the movement of progressively deeper waters, the net circulation itself is altered. In effect, the magnitude of surface water transport due to winds can be expected to increase (up to a point) as persistent winds alter the "normal" surface and near-surface circulation at progressively deeper depths.

Tidal Transport - Dispersion of a continuous oil spill within the Norton Sound-Bering Strait region will be enhanced by oscillatory tidal excursions. Tides in Norton Sound are primarily diurnal, with currents averaging 20-30 cm/sec. Diurnal excursions tend to be narrow elipses extending in an east-west direction over distances of 10-15 kilometers (6.2 to 9.3 miles). Therefore, an oil spill which continued over a complete tidal cycle could be spread a maximum distance of 15 kilometers (13 nautical miles) by tidal factors alone. In shallow water close to the Yukon Delta, currents and resultant excursions are thought to be less, but there are no direct observations to confirm this assumption. Offshore the area south of St. Lawrence Island appears to be a region of extreme tidal complexity, with areas of convergence, divergence and abrupt variations in velocity. This is believed to be a result of converging Arctic and Pacific tides (Pearson et al., 1980). Tidal circulation in this region will probably have little net effect upon the movement of spilled oil, but could increase lateral spread and possibly vertical mixing of oil in the water column due to current induced turbulence (BLM, unpub. data b).

Prediction of Pollution Transport - Prediction of pollution transport within the Norton Sound-Bering Strait region involves a number of transport mechanisms, all of which are variable with time and location. Generally, the tidal stage at which a spill occurred would usually be the most significant initial variable in determining a pollutant's trajectory.

Spreading and horizontal mixing processes also tend to enlarge the area of the spill. Surface spreading of an oil slick would be a particularly significant process in areas such as gyres where the surface slick could be retained for 1-2 weeks or more.

In the absence of winds, the net circulation will be the dominant factor controlling long range transport. Wind influence however, is likely to overshadow all other transport and dispersion processes and may, on the average, be the single most important force affecting surface oil transport. Not only does the wind have a direct influence on transport of surface oil, but the net circulation itself may be altered by persistent winds. Impingement upon shoreline areas frequently requires some onshore wind influence on either the net circulation or the surface slick. As an example of wind influence, a moderate onshore wind with a speed of 7.7 m/sec (15 knots) would cause an oil slick to drift onshore at a speed of roughly 23 cm/sec (0.45 knots), or about 11.5 km/day (10 nautical mi/day). During winter the dominant wind direction is usually from the north and northeast, thus inducing a net southwestward out flow of ice from Norton Sound. Under-ice circulation patterns during this period remain undefined.

<u>Ice</u> - The mechanisms involved in large scale transport of oil in ice have been discussed previously.

Spill Response and Containment

Fish and wildlife populations can be protected from the effects of an oil spill if the spill can be contained and cleaned up before it reaches these resources. In the event of an oil spill, it is imperative that cleanup proceed as soon as possible; that sufficient equipment be available to respond to the maximum projected spill; and that manpower and equipment be mobilized efficiently. At the present time, oil spill response and containment capabilities are limited by economic, environmental, logistic, and mechanical constraints, which, in many cases may preclude an effective cleanup operation except under ideal conditions. A review of existing oil spill containment and cleanup technology for the Norton Sound region reveals the following problems:

1. Most of the containment and cleanup equipment available for use during open water periods is only capable of operating in a maximum of 3 foot waves, 15 knot winds, and 1 knot currents (GOACO, 1977). Recent modifications may have expanded the capability of some equipment to operate in wave conditions approaching 6 feet (Barto, per. comm.) however, the actual application of such equipment remains for the most part untested. In the northern Bering Sea, extreme storm conditions in late summer and fall can be worse than those in the Gulf of Alaska. For Norton Basin the predicted maximum sustained wind speed is estimated to be 90 knots (100 mph) and the extreme wave height is estimated to be 32 meters (105 feet) (BLM, 1980). A regional composite averaging of median wind and wave data from the open water period of June through October shows that wind speeds equal or exceed 11 knots 44.3% of the time, and wave heights

exceed 3 feet 4.8% of the time (Brower et al., 1977). Tidal currents for most of Norton Sound are low, and range between 0.4-0.6 knots (20-30 cm/sec.), although in some nearshore areas tidal currents may be higher. In the Yukon Delta channels, tidal currents varying from 0.5 to 1.5 knots have been recorded. Offshore, the area north of St. Lawrence Island appears to be a region of extreme complexity for tidal currents with areas of convergence, divergence, and abrupt variations in velocity. Even under ideal conditions, conventional oil spill containment and recovery equipment cannot be expected to provide a removal efficiency much greater than 50% (Meikle, 1978).

2. Mobilization and deployment of oil spill containment and cleanup equipment will be difficult and time consuming. The Norton Sound-Bering Strait region has approximately 1931 kilometers (1200 miles) of coastline, but is essentially roadless east of Safety Lagoon. There are only three airstrips capable of accomodating large transport planes (Nome, Unalakleet, and Moses Point) and only one port capable of unloading heavy cargo (Nome). If a spill occurred near the center of Norton Sound it would take a vessel out of Nome approximately 5 to 7 hours to reach it, not including the time allowed for transportation of key personnel from Anchorage to Nome, and the time required to load equipment. If a spill were to occur in the eastern portion of Norton Sound where port facilities do not currently exist, vessel intercept times alone may approach 10 to 14 hours.

   Should a spill occur, personnel and equipment transported from Anchorage, Fairbanks, or Seattle would necessarily have to be unloaded in Nome or Unalakleet and be ferried to a spill site by helicopter, boat, or small aircraft. This will greatly increase the amount of time required to respond to a spill, and will be ineffective if weather conditions do not permit the use of such modes of transportation. It has been estimated that in this region during any time of the year there is a 30 percent chance that the cloud ceiling will be below 300 feet (BLM, 1980). Under adverse weather conditions it might require several days just to transport personnel and equipment to a spill site. During winter months the short days and long nights may cause additional delays in the ability to locate a spill and respond quickly, and the presence of ice is likely to impede most marine surface transportation.

3. In the event that weather conditions or the location of a spill make mechanical containment or cleanup impossible, dispersants may be used to protect fish and wildlife resources. Dispersants act to break apart an oil slick, reducing it to components which are more soluble within the water column, and which are therefore less likely to physically foul animal species or their habitats. However, there are several drawbacks to the use of dispersants.

The primary problem is that insufficient data is available on the effectiveness and toxicity of dispersants to make an objective decision regarding their use in Alaskan water. Certain dispersants and dispersant-oil mixtures can actually increase the amount of toxicity related damage resulting from a spill, thereby precluding their use in most cases. The Environmental Protection Agency (EPA) has published a list of approved dispersants; however, the presence of a dispersant on this list only signifies EPA's acceptance of the method used to test the dispersant and is not necessarily an endorsement of its innocuous nature. The second problem is that, dependent upon type, dispersants will only work under certain temperatures and sea conditions. If these conditions do not exist during a spill then dispersants will not work. Third, there has to be a means of delivering the dispersants to the spill site. Vessels, fixed-wing aircraft, and helicopters are all feasible, but weather and visibility must meet minimum standards to be effective, especially in the case of airborne systems. Fourth, dispersants are presently ineffective in ice infested waters.

4. Ice is normally present in the Norton Sound region 6 to 8 months of each year. Under such conditions, the effectiveness of most open water containment and recovery devices will be drastically limited once the concentration of ice exceeds roughly 10 to 20 percent (Logan, et al., 1975). Although oil removal operations could conceivably continue in the presence of brash or pancake ice (Meikle, 1978; ABSORB, 1980), it is likely that efficiency will be greatly reduced, and personnel safety factors may make such operations prohibitive.

Oil spill scenarios during winter conditions, as presented by the Alaskan Beaufort Sea Oil Spill Response Body (ABSORB), describe cleanup operations which largely address oil spilled within the shorefast ice zone. In such scenarios the ability to utilize heavy machinery and equipment is crucial in the contruction of containment berms or trenches, and for the physical collection and removal of oil spilled on top of the ice. However, during periods of seasonal transition, when ice is in active formation or degeneration, such operations would be impossible, and oil spilled at this time might flow unimpeded for several weeks before an attempt could be made to recover it. In Norton Sound both the strength and extent of the shorefast ice zone is very limited compared to that of the Beaufort Sea, and cleanup techniques such as those described will not be effective.

Should oil happen to be released in broken pack ice, it is doubtful that any of the methods currently employed during oil spill cleanup operations would provide more than a minor deterent to wide spread contamination; under such circumstances in situ burning is likely to be the only operational technique available. The reliability of this procedure however, is dependent upon several factors. The principal limitation to burning is that a minimum film thickness of roughly 0.5 cm is required to sustain combustion (Logan et al., 1975). During the Kurdistan spill off Cape Breton, the natural tendency for oil in pack ice was toward dispersion and dilution, with most observable oil occurring in the form of droplets or globules (C-Core, 1980). Burning would have been completely ineffective and was not attempted.

Furthermore, the effeciency of a burn varies directly with film thickness. For film thicknesses of about 2.0 cm the residues which remain after burning can be reduced to between 10 and 20 percent, while for marginal film thicknesses they can exceed 50 percent (Logan, et al., 1975).

Water temperature is another factor which will influence burn rate. Lower water temperatures will not only increase heat losses from spilled oil, but will also increase viscosity, therefore reducing the flow of oil to a burning area (USCG, 1978). Oil may then have to be reignited repeatedly to achieve anything approaching a comprehensive burn.

5. In a situation such as a blowout, or other loss of well control, it is probable that flaring techniques would be used to ignite the well if it became apparent that all other control methods were ineffectual or that on-scene personnel could not retard the movement of oil from the spill area. By flaring a blowout it is possible to burn up to 90 percent of the oil that is released, if ideal conditions exist at the time. However, the principal limitation of flaring is that it restricts all other activities in an area and, in the winter, fallout associated with this technique will tend to accelerate melt processes in the spring, thereby reducing the time available for surface cleanup (Logan et al., 1975).

In summary, it is apparent that current oil spill containment and cleanup technology is inadequate to provide protection to fish, wildlife, and sensitive habitats in the Norton Sound-northern Bering Sea region. The numerous hazards associated with each seasonal period, coupled with an almost total lack of support infrastructure, will require that extraordinary measures be taken to accelerate the development, acquisition, and application of more effective oil recovery technology and regional response capabilities. The time involved, and the capital investment required, will necessarily be extensive, however, present systems which rely on optimal climatic conditions in order to affect even a modicum of efficiency are clearly unacceptable.

A practical and effective solution to the current problem of protecting marine resources from the possibility of a marine oil spill, while allowing exploration, production, and transportation to proceed with a minimum amount of delay, would be to initiate a comprehensive analysis of current and projected oil spill capabilities in Norton Sound. Simultaneously, the technological and economic feasibility of developing additional equipment with the capability to clean up oil under all conditions prevailing in the Norton Sound-northern Bering Sea region should be evaluated. Where feasible, the development of more effective oil spill containment and cleanup equipment should be undertaken. In situations where it does not appear that it would be technologically feasible or economically sound to develop an additional containment and cleanup capability, the hazards of oil pollution could be minimized by scheduling operations with comparatively high risks of oil spillage during periods of maximum cleanup efficiency. For example, since it appears that oil is virtually unrecoverable once it is released in pack ice, well completion operations or tanker transport procedures should be suspended until cleanup conditions exist which will provide for a more favorable recovery rate. Until responsible measures of this nature are implemented, valuable fish and wildlife resources will continue to be imperiled by hazardous operations conducted during high risk periods. Additional recommendations designed to prevent, minimize or ameliorate the adverse impacts associated with oil pollution may be found in the Mitigating Measures segment of this section.

Biological Effects

The effect that oil contamination will have on marine organisms inhabiting the Norton Sound-Bering Strait region is difficult to quantify or predict. Usually a number of factors, acting both individually and in combination govern the consequences that an oil discharge may have on marine life (GESAMP, 1977).

It should initially be understood that subjective aspects of assessment sometimes make it difficult to achieve a consensus judgement on the ultimate impacts arising from a spill. Most researchers believe that areas supporting a high diversity of animal and plant life are subject to the greatest impact should an oil spill occur; others argue that locations with a low diversity are more fragile in terms of biologic perturbation, and therefore they would then receive the greatest impact (USCG, 1975). Other impact assessments may attempt to reconstruct an ecosystem model as existed prior to the discharge of oil as an indicator or standard with which to judge recoverability. This method can sometimes overlook the dynamic nature of a species population by assuming a stable state exists at a given point in time. Finally, mortality counts may be used to gauge the damaging results of an oil spill, although it is frequently the case that many animals die beyond the field of observation, or may expire through indirect means.

Long-term studies of several major oil spills have indicated that oil has the following effects on marine life: 1) direct kill of organisms through coating and asphyxiation, 2) direct kill through contact poisoning, 3) direct kill through exposure to water soluble toxic components of oil at some distance in space and time from the spill, 4) destruction of the sensitive juvenile forms, 5) destruction of the food sources of higher organisms, 6) incorporation of sublethal amounts of oil and oil products into organisms, resulting in failure to reproduce or reduced resistance to infection, or physiological stress, 7) contraction of diseases due to exposure to carcinogenic components of oil, 8) chronic low level effects that may interrupt any of the numerous biochemical or behavioral events necessary for the feeding, migration, or spawning of many species of marine life and, 9) changes in biological habitats (Blumer et al., 1970).

The following discussion will focus primarily on the effects of oil pollution on Alaskan species of fish and wildlife that are of commercial, subsistence or recreational importance. It should not be construed, however, that by limiting consideration to these highly visible species, the importance of other species of ecological value is diminished or ignored. Too little attention has been directed toward those organisms which are of no economic importance, but which nevertheless form a critical element of the food web upon which the commercial, subsistence or recreationally important species are dependent. In instances where information is lacking on a particular species present in the northern Bering Sea, an attempt has been made to include studies relating to other organisms possessing similar characteristics.

Marine Mammals - Studies into the effects of oil on marine mammals are limited and, as a result, much of the associated consequences are speculative in nature. Observations made at various oil spills (Tampico Maru, Torrey Canyon, Santa Barbara, West Falmouth, Shell, Argo Merchant, and Amoco Cadiz) do not indicate any major loss of marine mammals (Mackin, 1973; Nelson-Smith, 1973; NOAA/EPA, 1978, Geraci and St. Aubin, 1980). However, field observations may be grossly misleading since the majority of marine mammals which perish will probably sink to the bottom of the sea rather than drift to shore, making it difficult to document oil related mortalities.

It is anticipated that oil will not impact all marine mammals to an equal degree. Seals and walruses have been found to engage in a partitioning of available ice habitat and other resources, as is demonstrated by their dissimilar feeding habits, birth times, choice of birth sites, and the relative precocity of their young (Burns, 1970; Burns, 1980). Given such circumstances, oil released into a specific habitat or ice type might selectively impact one species over another. After conducting experiments on ringed seals, Smith and Geraci (1975) concluded that even intraspecific differences may exist which lend an unequal impact to oil contamination. Typically, older seals and seals in poor nutritional condition are likely to be more sensitive than younger healthy seals.

The toxic effects of direct oil contact and ingestion are not well known. Ingestion experiments in which ringed and harp seals were force fed 25-75 ml of Norman wells crude oil indicate that these quantities are not toxic on a short term basis (Smith and Geraci, 1975). However, it is not known what effect oil ingested by pups nursing from their mothers (coated with oil) will have on the young (Schneider, pers. comm.). Recent studies in which three polar bears where immersed in a simulated oil spill resulted in the death of two bears. Some indications of possible liver and nervous system disorders were reported after it was observed that the bears had ingested "considerable amounts of oil by licking their paws and legs" (Anchorage Times, 1980).

Ringed seals are thought to be particularly susceptible to the toxic components of oil released beneath landfast ice. Burns et al. (1980) feel that oil will tend to rise and accumulate in breathing holes and, since most holes do not penetrate completely through the snow to the air above, there will be a tendency for volatile fractions to accumulate in the air pockets and subnivian lairs which these seals utilize extensively. It is currently unknown whether an adult female exposed to this type of oiling would move out of an area of contamination and abandon a helpless pup, or would try to take the pup with her before it was sufficiently developed to leave the lair. Either of these responses are likely to increase the probability of pup mortality (Smith and Geraci, 1975).

The volatile components of oil also irritate sensitive membranes in the eyes and nostrils of seals. Smith and Geraci (1975) observed that ringed seals secrete tears (lacrimate) excessively and arch their backs when immersed in oil. Similarly, during the molting period, a loss of hair coupled with the shedding of an outer protective layer of cornified epidermis may also leave many pinniped species vulnerable to irritation by toxicants (Burns et al., 1980). Since the molt represents a period of considerable metabolic and psychological stress (Ronald et al., 1970 in Burns et al., 1980), any additional stress which might occur as a result of an oil spill could produce further unknown implications.

Seal pups are especially vulnerable to direct contact with oil. While they are being weaned, spotted, ribbon and ringed seal pups are relatively immobile and are dependent on woolly hair (lanugo) for insulation. The importance of the lanugo for thermoregulation decreases as thickness of the blubber layer increases. Oil adhering to a mothers coat, or oil which is deposited upon an ice floe surface would, if it came in contact with a pups lanugo coat, destroy its insulating value (Burns et al., 1980). If several square miles of landfast ice were oiled in a submarine spill a large number of pups might be expected to die of exposure.

The direct effects of oil on cetacean species are even less understood than those regarding pinnipeds. It has been suggested that blowholes could become plugged, eyes irritated, or whales might ingest oil when feeding on fish or plankton. Belukha and killer whales, like seals, feed on relatively large, individual prey animals, and probably would not ingest great amounts of oil. Conversely, bowhead whales which feed on small organisms filtered from the water, might also filter out any suspended oil as well (Fraker et al., 1978), thereby physically fouling the baleen plates which these animals use to strain food organisms. Gray whales which are also filter feeders, rely on benthic organisms for food and could be affected in a similar manner by sedimented oil particles.

According to Nelson-Smith (1973), it is doubtful that oil will adhere to whales because of their relatively smooth skin. Geraci and St. Aubin (1980), however, feel that cetacean skin may be particularly vulnerable to the noxious effects of surface contact with oil. This is due in part to its unique nature, consisting of epidermal cells rich in enzymes such as creatine kinase, sorbitol dehydrogenase, and aspartate aminotransferase. Additionally, cetacean epidermis is rich in vitamin C, the antioxidant properties of which may serve to protect the enzymatically active intracellular environment.

For whales involved in extensive seasonal migrations, as is typical of bowhead, belukha, and gray whales, oil may indirectly impact these species by causing a delay in migration, or possible avoidance of oil contaminated areas.

Birds - Oil pollution of any kind can cause the death of sea birds, shore birds, and waterfowl by drowning, exposure, starvation, poisoning, and increased vulnerability to predators. The death of marine birds caused by oil slicks and the water soluble fraction of oils are generally one of the earliest and most obvious indications of an oil spill impacting an ecosystem. Thousands of marine birds of all varieties are often affected by a large spill (Mackin, 1973). Diving birds which spend the majority of their life at sea are most susceptible to contamination by oil pollution; however, any bird that feeds or settles on the sea is vulnerable.

The direct effect of oil pollution on marine birds is well documented (Mackin, 1973; Nelson-Smith, 1973; GESAMP, 1977). In 1970, approximately 100,000 marine birds may have died after coming into contact with an oil spill off of Kodiak Island (FWQA, 1970; GESAMP, 1977). At least 10,000 birds, including alcids, ducks, gulls, and kittiwakes were also killed by oil apparently pumped from ballast tanks onboard tankers entering Cook Inlet during February and March of 1970 (Ohlendorf et al., 1978).

Oil spills from the wrecks of oil tankers such as the Torrey Canyon and Amoco Cadiz can have drastic long range effects on the productivity of marine birds. Populations of puffins, razorbills, guillemots, kittiwakes and other marine birds at the Les Sept Isles Sanctuary off the coast of Brittany dropped dramatically after the Torrey Canyon spill. Prior to the wreck approximately 2,000 pairs of puffins, 250 pairs of razorbills and 400 pairs of guillemots inhabitated two of the islands in the sanctuary. The next year the numbers decreased noticeably and had stabilized at about 800, 90 and 150 nesting pairs, respectively, preceding the spill from the Amoco Cadiz in 1978 (NOAA/EPA, 1978).

In many cases, the damage inflicted upon a colony of birds exposed to oil contamination arises not out of the number killed initially, but rather to what degree the breeding population has been affected. The reproductive output of a group of birds, year after year, has more effect on maintaining the population than does the random mortality of some individuals (Biderman and Drury, 1980). In this respect, the different reproductive strategies of seabirds become important when adult mortality increases (Hunt et al., 1980). Alcids (auklets, murres and puffins) lay a single egg and would require a long time for population recovery (Weins et al., 1979 _in_ Hunt et al., 1980). Kittiwakes, and other seabirds which lay multiple egg clutches have the potential to recover more quickly given optimal environmental conditions (Hunt et al., 1980).

It has been observed that birds can contaminate eggs with oil adhering to their feathers or by utilizing nesting materials containing oil. Albers (1977) and Hartung (1965) have found that small quantities of oil coated on mallard eggs significantly reduced their hatchability. Studies recorded by Biderman and Drury (1980) demonstrate that amounts of oil as small as 50 microliters (the amount in one-half drop from a average household eyedropper) may produce a 100% embryo mortality in treated eggs depending upon the type of crude oil applied. Similar results have been obtained with eggs of common eiders, glaucous and black-backed gulls, fork-tailed storm petrels and sandwich terns (Szaro and Albers, 1977; Patten and Patten, 1977; Manuwal and Boersma, 1978; Biderman and Drury, 1980). Additionally, the effects of oil on embryos are not confined to outright death. When just one microliter of oil is applied to day-old eggs, many of the embryos survive, but a significant number of them have deformities that include bill malformations, incomplete bone formation, and stunted growth. Many of these deformities would ultimately kill the chick (Biderman and Drury, 1980).

The effects of oil ingestion are not as apparent or as observable as the effects of oil on eggs. Laboratory studies with herring gull chicks have shown that ingestion of small doses of crude oil interfered with physiological functions which, when combined with other normal stresses encountered by birds such as food shortages and severe storms, could threaten their survival (Miller et al., 1978). Very small concentrations of oil were found to induce liver and kidney damage in mallard ducklings, and higher concentrations retarded some birds ability to develop flight feathers (Biderman and Drury, 1980). Behavioral changes may also occur as a result of birds ingesting oil. Harting (1965) found that when ducks were fed small doses of lubricating oil they stopped laying for two weeks.

It is possible that components of oil may be transmitted to birds by ingesting contaminated prey species. After the Amoco Cadiz spill, sea gulls were observed feeding on recently killed intertidal organisms along the coast (NOAA/EPA, 1978). Biderman and Drury (1980) have reported that radioactively "tagged" naphthalene components of oil were readily taken up and accumulated in tissues of mallard ducks which had been previously fed contaminated crayfish.

Perhaps the greatest threat that oil pollution presents to individual birds is the danger of physical fouling or plummage contamination. Depending upon temperature conditions, as little as seven grams of oil on the plumage of marine birds may cause death (Nelson-Smith, 1973). For birds which inhabit harsh environments, as is typical of the northern

Bering Sea, the amount of oil required to induce a series of events leading ultimately to death from heat loss may be much smaller.

Levy (1980) presents a general scenario for birds living a "precarious existence", where winter conditions coupled with a limited food supply result in considerable hardship: "Since survival for many of the birds is already marginal because of the stresses imposed by rigorous winter conditions, the additional stress from what might otherwise have been an insignificant amount of oil contamination may be sufficient to trigger a series of events that result in the bird's death. Under these conditions, a very small amount of oil-perhaps only a very small patch or even just a light stain-may degrade the insulating and water-repelling properties of its plumage to the extent that the bird is unable to cope with the accompanying increase in heat loss. In an attempt to maintain its body temperature, an involuntary shivering process is initiated and the bird's metabolic processes are accelerated (McEwan and Koelink, 1973 in Levy, 1980). These responses require an increased energy supply and, if this cannot be satisfied through increased food intake, the bird's fat reserves and subsequently its body tissues are rapidly consumed. As this occurs, the bird's average density decreases and it becomes progressively more buoyant. As a result, it becomes increasingly more difficult for diving birds to procure food, since both the depth to which they can dive and the time they can remain submerged are decreased. Although some may survive until environmental conditions become more favourable or until the damaged feathers are replaced, for most the spiral of increased energy demand coupled with reduced feeding efficiency soon leads to death by exposure and starvation. Under such conditions many birds might bear little or no evidence of oil contamination or cause of death, other than extreme emaciation" (Levy, 1980). Such an event might have occured in Bristol Bay during April of 1970 when an estimated 100,000 murres (diving birds) died as a result of unknown causes. In this case, the common denominator among all specimens observed was an emaciated conditon in which the average weight loss was greater than 25% (Bailey and Davenport, 1972).

Fish - Oil pollution may impact fish species through: 1) short-term lethal effects in which individuals are killed relatively quickly; 2) sublethal physiological effects which, depending upon their mode of action may eventually lead to death, and 3) hydrocarbon induced aberrant behavioral effects.

In studying the five life stages of Pacific salmon (egg, alevin, fry, juvenile and adult), it has been found that the emergent fry are the most sensitive to oil pollution (Rice et al., 1975, Moles et al.; 1979). Laboratory tests show that pink salmon fry are killed by oil concentrations as low as 1.41 ppm of the water soluble fraction of Prudhoe Bay crude oil. Conversly, pink salmon eggs were found to be fairly resistant in preliminary tests. Morrow (1973) has additionally reported that juvenile sockeye and silver salmon succumbed within a few hours after an oil slick was generated in their holding tank.

The eggs and early larval stages of species such as herring are particularly vulnerable to the effects of an oil spill since they are relatively immobile, and any oil which came ashore in the intertidal zone during periods of spawning could physically coat eggs and directly kill larvae. Herring larvae have reportedly been killed by a 96 hour exposure to 3 ppm of the water soluble fraction of Cook Inlet crude (Rice et al., 1976). In a Nova Scotia spill, an "intermediate oil" containing large amounts of aromatic hydrocarbons was identified as the cause of an extensive kill of herring.

Marine fish with floating eggs and planktonic larvae (such as Arctic cod) are also vulnerable to oil spills, since both eggs and larvae develop within the surface water layer. Currents which carry these early life stages would also transport oil, and would serve to keep both fish and pollutant in constant contact. Kuhnhold (1972) has reported that exposure to the soluble fractions of Venezuelan and Libyan crude oils resulted in total mortality of developing cod eggs. Researchers have found that over half of all the cod and pollock eggs collected from the area of the Argo Merchant spill were contaminated with oil droplets and tar. Additionally, a significant number of eggs collected were either dead (up to 46%) or contained grossly malformed embryos (18%) (Longwell, 1977).

Adult fish species which live and feed on the ocean bottom (demersal) are affected primarily by sinking oil which could become incorporated in bottom sediments, thereby providing a long term source of contamination. The LD50 (dosage at which 50% were killed) for Arctic cod has been recorded at 1.569 ppm $\pm$ 0.004 over an 8 day period (NWAFC, 1979); and Devries (1977) has reported that cod and pollock died within two hours after being exposed to 4 ppm of naphthalene, a toxic component of oil.

The sub-lethal physiological effects of hydrocarbon exposure can result in significant changes in an animal's ability to resist disease, find food, or avoid predators. Collectively, these changes may promote long-term population declines. This hypothesis is supported by a study which showed that small tidal creeks receiving petroleum wastes produced lower yields of fishery species than similar creeks not receiving such wastes (Spears, 1971).

Struhsaker et al. (1974) reported that exposure to sublethal concentrations of benzene induced abnormalities in developing herring embryos which, although not directly lethal, will in most cases eventually result in death. Larvae produced from cod eggs which were exposed to sublethal concentrations of the water soluble fraction of Venezuelan and Libyan crude oils were observed to be deformed (Kuhnhold, 1972). English sole held on contaminated sediments for over four months had a higher frequency of liver abnormalities and weight loss than did control fish in uncontaminated sediment (Malins et al., 1978). Results obtained by Cameron and Smith (1980) with herring eggs exposed to Prudhoe Bay crude oil and subsequently allowed to develop indicate that even larvae which appear outwardly normal may suffer ultrastructural damage such as mitochondrial disruption or intercellular degeneration.

Rice et al. (1977) indicate that sublethal concentrations of hydrocarbons may have substantial effects on the survival of salmon fry. Continuous exposure causes elevated metabolic rates and an increased demand for energy. This increased energy demand requires increased food intake which puts the fish at a disadvantage in its struggle for survival, especially if the stress persists over long periods of time.

Growth rates of pink salmon fry noticeably decreased after ten days exposure to very low levels of Prudhoe Bay crude oil (Rice et al., 1976). This is significant since the success of a year class of salmon is heavily dependent upon fry developing at precisely the correct rate to take advantage of the spring plankton bloom. Accelerated or retarded development could mean starvation and low survival rates for out-migrant fry.

Respiration rates of pink salmon fry increased markedly, when placed in water containing the water soluble fractions of hydrocarbons (Rice et al., 1976). This is an indication of stress and it is likely that a population of salmon which is constantly under stress from pollutants will develop more slowly and have a lower survival rate than an unstressed population.

A spill of diesel fuel in Puget Sound was found to have been the causitive factor inducing eye damage and blindness in coho salmon held in nearby rearing pens (Malins et al., 1978). It is probable that eye damage would greatly reduce the ability of salmon to find food and avoid predators. Rainbow trout (which are also salmonids) suffer skin, gill, liver and eye damage when exposed to the water soluble fractions of Prudhoe Bay crude oil (Hawkes, 1977). Skin and gill damage can increase susceptibility to infection from a wide range of bacterial, viral, or fungal pathogens which can commonly attack salmon.

It has also been found that marine fish can readily accumulate, or bioconcentrate, aromatic hydrocarbons in tissues when exposed through the diet, water column, or sediment (Varanasi and Malins, 1977 in Malins, 1980). The extent of accumulation differs in relation to such factors as species, hydrocarbon structure, route of administration, and environmental conditions. In various exposed marine fish, aromatic hydrocarbons have been identified in liver, dark and light muscle, brain, heart, gut, kidney, skin, eyes, gills, blood, bile, and mucus (Malins, 1980).

Bioconcentration is reported to be substantially higher for flatfish than for salmon (Roubal, et al., 1978). After a two-week exposure to the water soluble fraction of Prudhoe Bay crude oil, starry flounder accumulated bioconcentrations of petroleum hydrocarbons in liver and gill tissue in excess of 11,000 times the levels found in the exposure water (Roubal, et al.1978; Malins, 1980). In addition, it is also evident that flatfish tend to accumulate large concentrations of hydrocarbons when exposed to petroleum-rich sediments (Malins, 1980). McCain et al. (1978) reported that prolonged contact with hydrocarbons in the sediment at concentrations of 400 to 700 ppm induced both physiological and pathological abnormalities in English sole. Therefore, oil deposited on the ocean bottom through sedimentation or other means could significantly affect flatfish over time if they remain within a contaminated area.

The process by which complex mixtures of aromatic hydrocarbons are converted internally to other metabolic products is termed biotransformation. Thus far, studies have concluded that while most of the aromatic hydrocarbons themselves are readily depurated following exposure, metabolite concentrations in fish either continue to increase in tissues (eg. liver and muscle) (Roubal et al., 1977), or decline slowly over days or several weeks (Varanasi and Malins, 1977; in Malins, 1980). In many cases, the intermediate conversion product is an arene oxide which is known to cause lesions in the tissues of some mammals (Malins, 1980).

For fish exposed to oil pollution, the behavioral response initiated is likely to determine the degree to which they are impacted. When sculpins were exposed to seawater contaminated with 1 ppm naphthalene, exposed fish refused to feed. Their condition subsequently appeared to deteriorate over the course of the exposure (Devries, 1977).

The literature regarding the ability of salmonids to detect and avoid petroleum hydrocarbons is contradictory. Rice (1973) found that pink salmon fry demonstrated clear avoidance responses to oil concentrations as low as 1.6 mg oil/liter. However, in Canadian tests neither rainbow trout nor Atlantic salmon avoided lethal concentrations of phenol, a component of crude oil. Either reponse will produce adverse effects. If adult or juvenile salmonids enter an oil slick or contaminated area, they would probably be killed; however, avoidance of contaminated spawning and feeding areas could also have detrimental effects on both soluble fraction of oil may also impact adult and juvenile salmon by interfering with chemical signals that juveniles and fry use to locate food organisms, and which adults use to locate natal spawning streams. Malins et al. (1978) have reported that there appears to be no significant difference between unexposed salmon, and salmon exposed to hydrocarbons, in regard to their homing ability. However, exposed fish did exhibit a delay in return which was directly proportional to hydrocarbon concentration. Because salmon are engaged in complex migrations throughout their juvenile and adult stages, an alteration or delay in migration can threaten the survival of individuals, and continual interference could destroy certain populations. Salmon fry usually spend several weeks foraging close to shore before moving into deeper water. Chronic pollution, or a nearshore oil spill could prematurely force fry into deeper water where food is less abundant and exposure to predation is greatly increased.

The only published accounts of pollution affecting salmon migration involve adult Atlantic salmon. The upstream spawning of this species was affected by copper and zinc pollution in the Miramichi River. Although these salmon are highly motivated by instinct to migrate upstream, when they reached a sublethal concentration of toxicants they aborted their upstream migration and returned downstream without spawning. Other abnormal movements of adult Atlantic salmon were reported by observers following fish tagged with ultrasonic transmitters in the industrially polluted estuary of the river (Rice, 1973).

Rice et al. (1976) also reported that very young herring larvae apparently could not detect or avoid oil slicks and, as a consequence, significant mortalities resulted. This is supported by Kuhnhold (1972) who found that herring larvae were unable to avoid oil contaminated water, especially when oil was present as a dispersion. Similar results were obtained for English sole which do not discriminate between oiled and unoiled sediments

(NWAFC, 1979). In their natural environment, failure to detect and avoid oil slicks and other forms of oil pollution could result in increased mortality and declines in fish populations.

Recent experiments with teleost (bony) fish have demonstrated that polynuclear aromatic hydrocarbons (PAH's), which are common components of crude oil, can induce severe behavioral changes. In several instances, fish were observed swimming vertically and upside-down after being exposed to different concentrations of the specific PAH--2,6-dimethylnaphthalene (2,6-DMN) (NWAFC, 1980). In a natural environment, a fish exhibiting such aberrant behavior would both invite, and be defenseless against, predation.

Invertebrates - Bivalves - During the course of an oil spill, molluscs frequently suffer extensive mortalities. This is due in part to their inability to escape sinking oil, and because many of them are filter feeders which indiscriminately extract fine particles from the water, thereby ingesting oil which is present in the form of droplets, or oil which might be adsorbed on particulate material (GESAMP, 1977). Milan and Whelan (1978) studying the effect of oil pollution on salt marsh ecosystems report that benthic organisms, particularly oysters and mussels, demonstrated the greatest enrichment of petroleum hydrocarbons in comparison to other species which were present.

Very little information is available on the relative sensitivity of various life stages of molluscs to oil pollution. The planktonic stages (eggs, sperm, and larvae) may be the most vulnerable since they lack the protective shell of adults and therefore might be more susceptible to the toxic components of an oil spill. Renzoni (1975) subjected spermatozoa of the bivalve Mulinia lateralis to the water soluble fraction of a crude oil and then allowed them to fertilize untreated eggs, with the result that the percentage of fertilization was significantly reduced over that of the controls. Treatment with the water-soluble fraction caused a 62% mortality in the early ciliated embryos and a 59% mortality in older swimming larvae (Menzel, 1979). In laboratory tests, adult pink scallops, (Chlamys rubida) were killed by concentrations of Prudhoe Bay crude oil as low as 2.07 ppm (Rice et al., 1976).

Large scale mortalities in mollusc populations are commonly recorded following oil spills. During a jet fuel spill near Kodiak in 1970, thousands of cockles were killed, and an equal number were reported to be in very poor condition. The clams were subsequently declared a health hazard and residents were warned not to eat them. In a similar incident, a fuel oil spill in Washington resulted in the mortality of an estimated 300,000 razor clams over the course of a one week period (Tegelberg, 1964).

Sometimes the destructive aspects of an oil spill may not be completely realized until several years have elapsed following such an event. After the 1970 Chedabucto Bay spill, mortalities of the softshell clam (Mya arenaria) ranged from 19% to 73% in those areas sampled. Many clams were smothered by oil and died immediately. Others were contaminated with oil and came up out of the substrate where they were eaten by predators. In areas where the substrate became contaminated with oil, chronic mortalities in the clam population continued through 1976 (Thomas, 1976). A fuel oil spill in Searsport, Maine had much the same effect, where an original crop of 157 metric tons of the clam Mya arenaria existed prior to the discharge. Mortality was observed immediately after the spill, and a decline in numbers continued for the next three years. Twenty-five percent of the original population died within four months; 55% were dead 17 months later; and an 86% mortality figure was reported 3 1/2 years later. Only 22 metric tons of the original 157 metric tons remained as of August 1974 (Dow and Hurst, 1976).

Based on these reports, it is apparent that large oil spills do have the ability to induce mass mortality in clam populations. Death might occur for some subtidal species if the concentrations of soluble hydrocarbons in the water column reach the ppm level. If the substrate were contaminated, chronic die-offs could continue for several years, leaving many of the surviving clams contaminated and unfit for human consumption.

The sublethal impacts of oil pollution as they affect molluscs are varied. Mussels (Mytilus edulis) which were exposed to oil-contaminated sediment particles accumulated hydrocarbons in excess of 1,000 times exposure levels (Fossato and Canzonier, 1976). In one area which had been exposed to high levels of No. 2 fuel oil, the gonads of mussels failed to develop (Blumer et al., 1971).

Gilfillan (1973) demonstrated that low concentrations (1 ppm) of seawater extracts of crude oil reduced both the feeding and assimilation of carbon by blue mussels (Mytilus edulis) and marsh mussels (Mytilus demissus) while increasing respiration, the net effect being a significant reduction in the net carbon balance for both species. Gilfillan also suggests that the low energy reserves of the mussels might preclude the development of gametes and that this could account for the fact that the mussels that survived the West Falmouth spill failed to reproduce the following year (GESAMP, 1977).

Laboratory studies by Lee et al. (1972) indicate that the filtering ability of mussels may be inhibited when exposed to aromatic hydrocarbons. Depuration (cleansing) of petroleum hydrocarbons from clams and mussels depletes glycogen (carbohydrate) reserves and may cause tissue damage in certain organs. Conversely, incorporation of hydrocarbons in these animals would result in stress and tissue damage, and would undoubtedly reduce survival rates. In most depuration studies it has been found that there is an initial rapid discharge of accumulated petroleum hydrocarbons, however, a small concentration usually persists which may then be retained for very long periods (Lee, 1977). Mussels from the oil-polluted Lagoon of Venice still retained significant fractions of petroleum hydrocarbons even after 32 days of depuration (Fossato and Canzonier, 1976).

In Oregon, softshell clams and blue mussels from industrial dock areas were found to have accumulated high levels of carcinogenic benzo-a-pyrenes (a product of petroleum combustion) (Mix et al., 1976). High levels of carcinogenic petroleum compounds may cause tumors in animals and make them dangerous for human consumption. It has also been revealed that the incidence of gonadal tumors in soft-shell clams is much higher in areas exposed to oil contamination than from uncontaminated areas (LaRoche, 1973).

Rice and Karinen (1976) have noted that the growth rate in pink scallops was reduced as a result of exposure to the water soluble fraction of oil. However, studies conducted on oysters and snails in the Delta region of Louisiana where oil pollution is evident have shown no diminution in growth or numbers (Mackin and Hopkins, 1962).

There is evidence to indicate that, as a result of selection, mussels from chronically polluted areas are more resistant to oil pollution than mussels from pristine areas (Kanter et al., 1971). This illustrates the danger in assuming that because a certain organism lives in a polluted environment, such as occurs near the oil seeps at Coal Oil Point, California, other individuals of the same species will also be resistant. It may have taken thousands of years to develop that resistance.

Limited observations concerning aberrant behavior in molluscs exposed to oil, or the water soluble fraction of oil, indicate that exposure to low levels of contamination may increase predation and impair reactions to environmental stimuli. When the clam *Macoma baltica* was exposed to the water soluble fraction of Prudhoe Bay crude oil, it reacted by burrowing to the sediment surface (Taylor and Karinen, 1977). In nature, any clam which is exposed on the surface of sediments would probably be eaten by predators or, in the intertidal region, die from exposure. After exposure to oil-water emulsions of No. 2 fuel oil and Louisiana crude, softshell clams (Mya arenaria) exhibited the following behavioral sequence: increasingly impaired activity, immobilization, and finally death (Stainken, 1977). Continuous exposure to low levels of hydrocarbon pollution would probably result in declines in clam, scallop and mussel populations.

Crab and Shrimp - Of the four life stages (egg, larvae, juvenile, and adult) of crab and shrimp, the planktonic larvae of both classes are the most sensitive to oil pollution. Sensitivity to oil has been found to be related to molting, and larvae molt more frequently than adults (Rice et al., 1976 Caldwell et al, 1977). Planktonic larvae would be affected by oil slicks and the water soluble fractions of oil, whereas epibenthic adult crab and shrimp would be affected by the water soluble fractions and sinking oil. Both crab and shrimp species are especially vulnerable to water soluble hydrocarbons because of the large volumes of water which they absorb during the molting process. Sinking oil can affect them through direct toxic effects, physical coating, contaminating food organisms, or by interfering with chemical signals crab and shrimp use to locate food or sexual partners.

Typically, oil concentrations in the 1-4 ppm range are sufficient to cause significant mortalities in both adult, and larval, crab and shrimp populations after 96 hours of exposure. Rice and Karinen (1976), however, feel that many of the 96 hour TLM (Median Tolerance Limit: the concentration required to kill 50% of the test animals within the specified period of time) levels given in the literature may be too high, since many crabs expire after the 96 hours have elapsed.

Tanner crab exposed to the water soluble fractions of Cook Inlet crude lost a substantial number of legs (Karinen and Rice, 1974). Oil concentrations as low as 0.32 ml oil/liter were sufficient to evoke this response. Brief exposure of premolt tanner crab 1 to 4 weeks before molting appeared to have a detrimental effect on molting. After exposure to the water soluble fraction of Cook Inlet crude (1.2 ppm) for 48 hours, molting success was reduced to zero. For developing crabs failure to molt will usually result in death.

Exposure to low concentrations of the water soluble fractions of Cook Inlet crude can also cause a significant increase in the respiratory rate of king crab. The soluble aromatic fractions may accumulate in gill, muscle, or gut tissue up to 1200 times background levels (Rice et al., 1976). Crude oil did not cause significant mortality in king crab eggs, however, there was some indication that larval development might be affected (Rice and Karinen, 1976). Meyers (1976) found that several samples of shrimp taken after a drilling operation exhibited indications of petroleum contamination, whereas samples taken before drilling had shown none.

Oil in very low concentrations, which causes no direct mortality, may have adverse effects on individuals and populations. Individuals subjected to sublethal exposures may undergo "ecological death" if they are incapable of adjusting to natural stresses in their environment as a result of this exposure. For example, a tanner crab which lost a substantial number of legs after a short exposure to oil would probably not survive in the natural environment. Any factors which affect molting in crab also affect growth rate. Erosion of gill tissue and cellular damage will reduce the animal's physical well-being, increase its chances for infection, reduce its growth rate, and generally decrease its chances for survival. Accumulation of aromatic hydrocarbons in crab and shrimp tissue would not only have an adverse effect on the animal, but could also make it unfit or dangerous for human consumption. This would be especially true for carcinogenic fractions such as benzo-a-pyrenes. To summarize: chronic exposure may not result in direct short-term mortality but, by reducing birth rates and increasing the death rate, may induce a subtle trend which would result in a general decrease in crab and shrimp populations.

Crustaceans, like other organisms, rely to varying degrees on behavioral patterns for survival. There is a growing body of information indicating that, in aquatic ecosystems, behavior such as feeding, mating, habitat selection, migration, escape, and orientation may be dependent on detection of trace amounts of organic compounds. There is also mounting evidence that the mechanism by which sperm cells are attracted to an egg is based on chemical signals from the egg. Consequently, there has been concern that petroleum contamination, even at very low levels (in the part per billion range), may disrupt chemically-mediated behavior patterns of marine organisms through masking or mimicking chemical clues or by disrupting sensory physiological mechanisms (Boesch, 1973). Krebs (1973) reported that after the West Falmouth oil spill male and female fiddler crabs (Uca pugnax) exhibited breeding display colors, and males exhibited threat postures even though the breeding season was over. Takahashi and Kitteredge (1973), studying the effects of hydrocarbons on the rock crab Pachygrapus crassipes, found that the water soluble extracts of two crude oils inhibited the feeding response and the mating stance of males when exposed to the females sex pheromone. This inhibition was found to persist in concentrations below the parts per billion range. Further studies revealed that monoaromatic hydrocarbons were effective as inhibitors of chemoreception for relatively short periods of time - 30 minutes to 1 hour; however, polynuclear hydrocarbons (such as naphthalene and binaphthyl) inhibited the crabs for 8 to 11 days, and anthracene induced inhibition lasted 13 days (Williams and Duke, 1979). Rice et al. (1976) found that dungeness crab larvae did not avoid oil slicks, but would repeatedly swim up into them until overcome by the toxic effects. Exposure to 0.1-1.0 ppm of the water soluble fraction of No. 2 fuel oil adversely affected chemoreception in lobsters (Homarus americanus). This interference was manifested by inappropriate feeding, searching, escape, and aggressive behavior, and by abnormal neuromuscular control (Atema, 1977). Failure to find food, inappropriate responses to environmental stimuli, failure to find mates, and a change in time of spawning could result in significant reductions in crab and shrimp populations.

Marine Plants - Observations following the wreck of the Amoco Cadiz showed that macroalgae (marine plants) on exposed rocks tended to retain oil long after it had been removed from the bare rocks by wave action. Not only were the plants affected, but the retention of oil by the macroalgae probably increased the time of exposure between the oil and organisms living beneath the plants. Mortality of intertidal organisms was most noticeable during the first two months after the oil reached the coastal environment rather than immediately after the spill. Many of the affected plants did not appear to be dead, although chronic effects could not be detected (NOAA/EPA, 1978).

Studies of the marine algae Fucus have shown that small amounts of oil (200 ppb or less) cause an apparent stimulation of growth in juvenile plants; however, concentrations above this level produced increasingly deleterious effects on plant growth. In addition, when Fucus receptacles were placed in oil solutions during gamete release all germination ceased even when only minute quantities of oil were present (Steele, 1977). This would imply that plants exposed to chronic sources of oil pollution might have little chance of reproducing and therefore could be eliminated from an area subjected to such conditions.

Hydrocarbon Tainting of Fisheries Products - Tainting of fisheries resources is a potentially serious problem in areas subject to either chronic or acute oil pollution. Crustaceans, molluscs, and fish which are exposed to oily conditions frequently acquire an oily or objectionable taste. Environmental Protection Agency (EPA) criteria governing tainting in fisheries products state: "materials should not be present in concentrations that individually or in combination produce undesirable flavors which are detectable by organoleptic tests performed on edible portions".

Most human taste sensations are produced by a combination of taste and smell. The nose is a very sensitive organ and can detect surprisingly low concentrations of oil. Diesel oil can be detected at concentrations of .0005 ppm. Other hydrocarbon compounds which have caused tainting include toluene, phenols, napthol, kerosene, toluene dibenzothiophenes, napthenic acids, mercaptans, tetradecans, dispersants, methylated napthalenes and outboard motor fuel exhaust (GESAMP, 1977; Thurston et al., 1979). Although of hydrocarbon origin, these compounds may also produce unusual tastes that are not, in a sense, "oily".

Petroleum hydrocarbons can enter marine organisms through the gills, skin, or permeable intestinal lining (Hawkes, 1977; Teal, 1977). Water soluble fractions of petroleum and contaminated food substances appear to be the major source of hydrocarbon contamination in marine organisms (Teal, 1977). Hydrocarbons can be concentrated in certain tissues such as gills, lipids, liver, muscle, and brain at 1-10,000 times the level found in food substances or in the water (Rice et al., 1976; Lee, 1977). By this mechanism comparatively low levels of hydrocarbons in molluscs, fish, and shellfish, can be concentrated until they reach objectionable levels (Stainken, 1977).

Laboratory studies with two fish species suggest that as little as 0.01 ppm of oil in seawater can produce an odor in fish flesh (Nitta, 1970). By comparison, hydrocarbon levels commonly reach 50 ppm in discharged formation waters, 0.25 ppm under oil slicks, and up to 1650 ppm in sediments (Brooks et al., 1976; Longwell, 1977; Blumer and Sass, 1972). If the source of contamination is removed; organisms do have the ability to depurate (become cleansed of the contamination). However, total depuration of hydrocarbon contamination may take anywhere from five days to four years to complete depending on the species (Lee, 1977).

A study was undertaken in Louisiana to determine if the water soluble fractions of crude oil could affect the taste of Gulf shrimp (Penaeus aztecus and Penaeus setiferus). It was found that the panel of taste testers could consistently detect an "oily" taste in shrimp which had been exposed to a concentration of 49 ppm crude oil in sea water for 48 hours. Some judges could consistently detect an "oily" taste in shrimp which had been exposed to a concentration of only 5 ppm crude oil (Knieper and Culley, 1975). The oily taste in shrimp persisted for 10 days after the shrimp were removed to clean water.

Tainting of seafoods has been of great concern to fishermen for many years due to the fear that tainted catches will be refused upon delivery at the processing plant. The contamination of seafoods by oil is well documented. Following the West Falmouth spill of No. 2 fuel oil, the scallop and oyster fishery was closed for two years on the grounds that a health risk existed after identifiable oil components in shellfish tissue were found (GESAMP, 1977). Grant (1969) reported that from just one area near Brisbane, Australia, 78 short tons of sea mullet were lost to condemnation due to a "kerosene-like" taint. Following the spill of Bunker C oil from the Arrow, the clam fishery in Chedabucto Bay remained closed for four years (GESAMP, 1977). A spill of 1,000 gallons of Venezuelan crude oil in Halifax Harbor caused the tainting of 1,800 lbs of lobsters which were being held in storage tanks (Whitman, 1975) Additional information on tainting is contained in the GESAMP (1977) publication Impact of Oil on the Marine Environment.

Based on the previous information, it is possible that in the event of an oil spill, or chronic low level oil pollution, tainting of marine fisheries resources in the Norton Sound-Bering Strait region could occur. Because tainted fisheries resources would be impossible to sell, this could result in major economic losses to fishermen. In addition to the problem of actual seafood tainting, there are two other problems associated with tainting which could also have a significant effect on the fishery. Consumers may refuse to purchase or consume seafood from areas known or believed to be contaminated by oil pollution, and fishermen may refuse to fish or risk fouling their gear in areas known or believed to be contaminated. Even though little actual tainting may occur, major economic losses can result through losses in marketing ability of the area's seafood products, or through a loss of fishing time.

Table 21 Effects of oil pollution on fish, wildlife, aquatic plants and their habitats

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Marine Mammals					
Acute/Toxic Effects					
Northern Fur Seal (*Callorhinus ursinus*) Sea Otter (*Enhydra lutris*) Walrus (*Odobenus rosmarus*) Weddell Seal (*Leptonychotes weddelli*) Bearded Seal (*Erignathus barbatus*) California Sea Lion (*Zalophus californianus*)	Kooyman, Gentry and McAlister, 1976	bioassay	Prudhoe Bay crude	10 to 20 ml (brushed on pelts)	Small amounts of crude oil have large effects on animal pelts which utilize fur for insulation, and no effects on pelts of animals that depend on fat for insulation.
				100 ml (brushed on pelts)	In living animals, light oiling of approximately 30% of the pelt surface area resulted in a 1.5 fold increase in metabolic rate of sea otters and fur seals while immersed in water of varying temperatures. The effect can last 2 weeks. Any contact with oil at any time of the year would have a profound influence on the health of individual northern fur seals.
Harp Seal (*Phoca groenlandica*) Northern Fur Seal (*Callorhinus ursinus*) Sea Otter (*Enhydra lutris*) Walrus (*Odobenus rosmarus*) Bearded Seal (*Erignathus barbatus*) Weddell Seal (*Lepthonychotes weddelli*) California Sea Lion (*Zalophus californianus*)	Kooyman, Davis, and Castellini, 1977	bioassay	Prudhoe Bay crude	10 to 20 ml (brushed on pelts)	Small amounts of crude oil greatly reduce the effectiveness of animal pelts which utilize fur for insulation. It was concluded that light oiling causes detrimental effects in the ability to thermo-regulate body temperature, particularly in sea otters and fur seals, and that this could then lead to hypothermia, thermal effects on other pinnipeds which utilize fat for insulation would be minimal. Removing the oil from the pelt did not improve its insulating capacity.

ppm = parts per million
ppb = parts per billion
LC50 = concentration required to kill 50% of the test animals
TLM = median tolerance limit - the concentration required to kill 50% of the test animals within certain time limits

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Sea Otter (*Enhydra lutris*) Northern Fur Seal (*Callorhinus ursinus*) Harbor Seal (*Phoca vitulina*)	Kenyon, 1972	oil pollution	diesel oil	oil slick	Sea otters died after several hours of exposure to a thin layer of oil because they have no blubber for insulation. Two dead harbor seals coated with oil were found in Tacoma Harbor. A harbor seal and northern fur seal both covered with oil were weak and thin. Both recovered after cleaning and a program of force feeding.
Ringed Seal (*Phoca hispida*)	Smith and Geraci, 1975	bioassay	Norman Wells crude oil	oil slick (1 cm thick)	Three seals immersed in crude oil died within 71 minutes. The deaths apparently occurred from stress.
Polar Bears (*Ursus maritimus*)	Anchorage Times, 1980	oil immersion	unknown	surface slick	Two bears died as a result of being immersed in oil. Indications of possible liver and nervous system disorders were reported after it was observed that the bears had ingested "considerable amounts of oil by licking their paws and legs".
Physiological Effects					
Harp Seal (*Phoca groenlandica*) Ringed Seal (*Phoca hispida*)	Smith and Geraci, 1975	bioassay	Norman Wells crude oil	oil slick (1 cm thick)	Ringed seals immersed in oil for 24 hours showed enzymatic and histologic evidence of kidney damage as well as liver involvement. However, these effects were reversible. It is not known what effects chronic exposure of oil will have on seals. Most of the seals experienced eye irritation which could result in permanent eye damage if the exposure were chronic.
			Norman Wells crude (NW) Mildale crude oil (MC) Saskatchawan crude oil (SC)		NW crude oil was brushed on the hair of harp seals. The next day they were recoated in the same manner using MC and SC oil. No negative effects resulted.
			.547 ml ^3H benzene and 125 ml Norman Wells crude oil mixture	25 to 75 ml	Ringed seals were force fed 5 ml of the oil mixture over a 5 day period for a total of 25 ml of crude oil. Harp seals were fed one dose of oil ranging from 25 to 75 ml. Damage to both species of seals was negligible indicating that an ingested dose ranging from 25 to 75 ml of crude oil was not irreversibly harmful. Chronic intake of crude oil may cause permanent liver and kidney damage.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Pinnipeds	Burns et al., 1980	discussion	none	none	Burns (1980) feels that oil spilled beneath landfast ice will tend to rise and accumulate in breathing holes, causing volatile fractions to accumulate in air pockets and subnivian lairs of ringed seals. Also during the molting period a loss of hair coupled with a shedding of the outer protective layer of cornified epidermis may leave many pinnipeds vulnerable to skin irritation from hydrocarbons. It is also hypothesized that oil adhering to a mothers coat would, if it came in contact with a pups lanugo coat, destroy its insulating value.
Behavioral Effects					
Ringed Seal (Phoca hispida)	Smith and Geraci, 1975	bioassay	Norman Wells crude oil	oil slick (1 cm thick)	Ringed seals arched their backs, a sign of distress, upon encountering the surface of oil-coated water.
Northern Fur Seal (Callorhinus ursinus) Harbor Seal (Phoca vitulina)	Kenyon, 1972	oil pollution observations	diesel oil	oil slick	Northern fur seals and harbor seals appear to lose their appetite when coated with oil.
WHALES	Insufficient data is available to clearly document the impact of oil on whales.				
MARINE BIRDS					
Acute/Toxic Effects					
Mallard (Anas platyrhynchos) Pekin (domestic mallard)	Hartung and Hunt, 1966	bioassay	diesel oil, cutting oil additive containing 30% chlorine and 10% phosphorus, cutting oil formulated with 10% of the above additive and 10% triglycerides and 80% mineral oil.	various doses	LD50 values for prestressed ducks fed various dosages of the oil, oil mixture and additive were: 4 ml/kg-diesel oil; 3 ml/kg-cutting oil; 1 ml/kg-cutting oil additive. The magnitude of mortality from oil ingestion will depend upon the type of oil involved and the extent of any additional stress.
Physiological Effects					
Mallard (Anas platyrhyncos)	Hartung, 1965	bioassay	lubricating oil	2 - 35.9 g	After mallard eggs were coated with small amounts of oil hatchability was reduced to 21% compared to 80% for un-oiled eggs.
Mallard (Anas platyrhyncos)	Albers, 1977	bioassay	No. 2 fuel oil, 9 paraffin compounds propylene glycol	various doses	50 ul of propylene glycol added to the surface of eggs reduced hatchability to 80%. 50 ul of the paraffin mixture reduced hatchability to 72%. Fuel oil dosages of 5, 10, 20 and 50 ul of fuel oil reduced hatchability to 45%, 12% 2% and 0, respectively. Hatchability for the control group was 88%. All doses killed the majority of mallard embryos within 72 hours.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Common Eider eggs (Somateria mollissima)	Szaro and Albers, 1977	bioassay	No. 2 fuel oil, propylene glycol	various doses	Hatching success was 96% for the eggs treated with 20 ul propylene glycol, 96% for the controls, 92% for the eggs treated with 5 ul of oil and 69% for the eggs treated with 20 ul of oil.
Mallard (Anas platyrhyncos) Common Eider (Somateria mollissima) Louisiana Heron (Hydranassa tricolor) Great Black-Back Gull (Laurus glaucoides) Laughing Gull (Laurus atricilla) Sandwich Tern (Spp. unknown)	Biderman and Drury, 1980	observation, gas chromotography mass spectrometry	unknown oil	varied	Effects of oil on eggs: When 50 ul (micro liters) of oil was applied to mallard eggs mortality was 100%; with 5 ul applied, mortality ranged from 25% to 90% depending on the kind of crude oil used. Other species exhibiting a similar response include Louisiana heron, common eider, great black-backed gull; laughing gull and sandwich tern. 20 ul of oil applied to great black-backed gulls eggs reduced hatching success to 50% of control group, and the success of the surviving chicks to fledge was 33% of untreated egg clutches. Mortality effects were toxically derived rather than through a smothering effect. If oil was allowed to weather for 2 or 3 wks. the toxic effect was reduced but mortalities of embryos still existed. When just 1 ul of oil was applied to eggs, many of the embryos survived, but a significant number were deformed. Effects of oil ingestion: Adult birds are able to eat large quantities of oil without exhibiting any ill effects. However, ducks in a stress situation died when oil was introduced in their diets. Mallard ducklings sustained kidney and liver damage when ingesting small concentrations of oil. Petroleum seemed to retard maturation of egg cells. Oil residues can be transmitted through the food chain: "Tagged" naphthalene was readily taken up by ducks and accumulated in several tissues of their bodies after ingesting polluted crayfish.
Seabirds	Levy, 1980	observation, gas chromotography ultraviolet spectrophotometry	Argo Merchant and Grand Zenith heavy fuel oil	varied	Small amounts of oil on a birds plummage may trigger a series of events which can ultimately lead to starvation or death. Such events would include loss of thermoregulation and a decreased ability to obtain food.
Herring Gull chicks (Larus argentatus)	Miller et al., 1978	oral ingestion experiment	Kuwait or South Louisiana crude	No. 2 ml dose (dose equivalent to 0.3 ml per kilogram of body weight)	Dose caused cessation of growth, osmoregulation impairment, and hypertrophy of hepatic, adrenal, and nasal gland tissue in birds living in a simulated marine environment. Such findings suggest that crude oil causes multiple sublethal effects that might impair a birds ability to survive at sea.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Fork-tailed Storm Petrels (Oceanadroma furcata)	Manuwal and Boersma, 1978	application of oil to eggs	North Slope crude oil	0.5 ml dose per egg	Surface application of crude oil appeared to disrupt normal development of embryos, possibly by interfering with normal gas exchange or by leaching toxic hydrocarbons through the shell. In some cases oiled eggs were abandoned by parents.
Common Murres (Uria aalge)	Bailey and Davenport, 1972	observation	unrecorded	unknown	A large number of common murres were found dead or dying along beaches of the Alaska Peninsula and Unimak Island. Traces of oil were found in some locations but the birds were mostly unoiled and suffering from extreme emaciation. It is possible that very minor amounts of oil might have induced a loss of thermoregulation causing an increased expenditure of energy which resulted in a sharp decrease in body weight and an inability to adequately procure food.
Glaucous-Winged Gull eggs (Larus glaucescens)	Patten and Patten, 1977	bioassay	mineral oil North Slope crude oil	1 cc/egg	Crude oil applied to the surface of 150 eggs reduced hatchability to less than 1%. Mineral oil applied to the surface of 75 eggs reduced hatchabiltiy to 15%. 77% of the untreated eggs hatched.
Herring Gulls (Larus argentalus) (Larus glaucescens)	Patten and Patten, 1978	observation	Prudhoe Bay crude oil	1 cc/egg surface applications	Results indicate that very small amounts of oil (1 cc) applied to gull eggs at early stages of incubation lead to high embryonic mortality. Embryonic resistance to petroleum exposure increases with the duration of incubation.
Behavioral Effects					
Mallard (Anas platyrhyncos)	Hartung, 1965	bioassay	lubricating oil	various doses	Three ducks fed 2 grams of lubricating oil per kilogram of body weight ceased laying eggs immediately and did not resume until two weeks had passed.
Glaucous-Winged Gull eggs (Larus glaucescens)	Patten and Patten, 1977	bioassay	mineral oil, North Slope crude oil	1 cc/egg	Adult gulls continued to brood unhatched eggs (treated with oil) 20 days longer than normal with only 4% producing replacement clutches of eggs.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
CRAB					
Acute/Toxic Effects					
Tanner Crab juveniles (Chionoecetes bairdi)	Karinen and Rice, 1974	bioassay 48 hr TLM	Prudhoe Bay crude oil	.056-1.00 mg oil/ liter of seawater	The median tolerance limit for both premolt and postmolt tanner crabs was estimated to be .56 mg oil/liter. Molting success of premolt crabs after exposure to .32 ml oil/liter was significantly lower than the molting success of control crabs. Failure to molt usually resulted in death.
King Crab larvae (Paralithodes camtschatica)	Mecklenburg et al., 1976	bioassay 96-120 hr LC50	Cook Inlet crude-water soluble fraction (WSF)	0.93-4.75 ppm total hydrocarbons	Molting success in king crab larvae was reduced to almost zero by exposure to 1.2 ppm WSF for 48 hours. Failure to molt usually results in death. 50 percent of the larvae tested died within 96 hrs, and 120 hrs, after being exposed to Cook Inlet crude oil concentrations of 1.37 ppm and .93 ppm of respectively.
Dungeness Crab (Cancer magister)	Caldwell et al., 1977	bioassay	Cook Inlet crude-water soluble fraction, and seawater solutions of benzene or naphthalene		Toxic effects were observed at levels as low as .0049 mg/l for the crude oil, and .13 mg/l and 1.1 mg/l for the benzene and naphthalene, respectively.
Adult and larval King Crab (Parlithodes camtschatica) and Dungeness Crab (Cancer magister)	Rice et al., 1976	bioassays	Cook Inlet crude oil No. 2 fuel oil, Prudhoe Bay crude oil	water soluble fractions of oils measured as ppm of oil by IR method	96 hr TLM's for adult king crab were 2.35 ppm and 4.21 ppm for Prudhoe Bay and Cook Inlet crude oil, respectively. 96 hr TLM for No. 2 fuel oil was 5.10 ppm. Tanner crab larvae were killed by 8 ppm of oil after 96 hrs of exposure. Exposure to WSF of Cook Inlet crude oil at low levels (.9 ppm - 3 ppm) caused moribundity in tanner and dungeness crab larvae. Moribundity would usually last for several days before an animal would die. Toxicity of hydrocarbons is greater during molting. Crab larvae molt more frequently than adults and are, therefore, more sensitive to hydrocarbon pollution.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
PHYSIOLOGICAL EFFECTS					
Tanner Crab (*Chionoecetes bairdi*)	Karinen and Rice, 1974	bioassay 48 hr TLM	Prudhoe Bay crude	0.32-0.56 ml oil/liter of seawater	Postmolt crabs lost a substantial number of legs due to exposure to oil levels as low as .32 ml oil/liter. Some larvae failed to molt but survived. Brief exposure of premolt tanner crab 1 to 4 weeks before molting probably has a detrimental effect on molting.
King Crab (*Paralithodes camtschatica*)	Smith and Bonnett, 1976	bioassay	Cook Inlet crude	low concentration of the WSF of Cook Inlet crude oil	After 6 days exposure to the water soluble fraction of Cook Inlet crude oil crab gills showed: (1) extensive vacuoloation, (2) nucleus change, (3) cytoplasm modifications, (4) fewer mitochondria, (5) swollen rough endoplasmic reticulum cisternae and (6) distorted interdigitations along later and basal cell surfaces. Vacuolation was also present in blood cell cytoplasm, and the perinuclear space was enlarged. Some of these changes indicate morphologic damage related to the altered metabolic response to sublethal crude oil exposure.
King Crab (*Paralithodes camtschatica*) and Tanner Crab (*Chionoecetes bairdi*)	Rice et al., 1976	bioassay	Cook Inlet crude	less than 4.21 ppm WSF	Exposure of juvenile and adult king crab to the water soluble fractions of Cook Inlet crude resulted in significant decrease in their respiration rate. Specimens recovered after removal to clean water. When placed in water containing the WSF of Cook Inlet crude oil, king crab larvae accumulated significant quantities of aromatic hydrocarbons. Biomagnification of some compounds up to 1,260 times ambient levels occurred. Crabs depurated within 96 hrs after removal to clean water.
King Crab (*Paralithodes camtschatica*) and Tanner Crab (*Chionoecetes bairdi*)	Rice and Karinen, 1976	bioassay	Cook Inlet crude oil	water soluble fractions	Spawning female king and tanner crab were exposed to the water soluble fractions of Cook Inlet crude oil. Preliminary findings indicate that the oil had little effect on the water hardening of the eggs or the attachment of the eggs to the pleopodal setae; however, development may be affected.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Behavioral Effects					
Dungeness Crab (Cancer magister)	Rice et al., 1976	bioassay	Cook Inlet crude oil	oil slick	Dungeness crab larvae did not appear to detect oil and would repeatedly swim up into surface slicks. Observations of larvae strongly suggest that larvae are oblivious to the presence of oil until affected physiologically by toxic concentrations.
Fiddler Crab (Uca pugnax)	Krebs, 1973	observation	No. 2 fuel oil	spill	It was reported that male and female crabs in the area affected by the spill exhibited breeding display colors, with males further exhibiting threat postures even though the breeding season was over.
SHRIMP					
Acute/Toxic Effects					
Coonstripe Shrimp (Pandalus hypsinotus) Humpback Shrimp (Pandalus goniurus) and Pink Shrimp (Pandalus borealis)	Rice et al., 1976	bioassay	Prudhoe Bay crude, Cook Inlet crude and No. 2 fuel oil	water soluble fraction	96 hr TLM's of 3 species of shrimp for WSF's of Cook Inlet crude and No. 2 fuel oil (ppm of oil). Species — Cook Inlet Crude — No. 2 Fuel Oil Humpback Shrimp — 1.98 — 1.69 Coonstripe Shrimp — 2.72 — - Pink Shrimp — 2.43 — - The 96 hr TLM for humpback shrimp exposed to the WSF's of Prudhoe Bay crude oil was 1.26 ppm. 2.4-1.87 ppm of the WSF of crude oil would induce moribundity in coonstripe shrimp larvae. Moribund larvae showed some motion but were unable to move and were destined for death. Shrimp larvae were more sensitive to the WSF of hydrocarbons than adults. This may be due to the frequency of molting.
Coonstripe Shrimp (Pandalus hypsinotus)	Vanderhorst et al., 1976	flow through bioassay	No. 2 fuel oil	water soluble fraction	Shrimp LC50 values were .8 mg/liter as compared to values of 1.5 to 50 mg/liter reported for static bioassays.
Coonstripe Shrimp (Pandalus hypsinotus)	Mecklenberg et al., 1976	bioassay 6-144 hr	Cook Inlet crude oil-water soluble fraction (WSF)	0.25-7.94 ppm	Molting coonstripe shrimp larvae were 4 to 8 times more sensitive to the WSF of Cook Inlet crude than intermolt stage I and II. 1.15 and 1.37 ppm of total hydrocarbon severely inhibited molting (10% molting success) in exposures of 24 hrs or longer. Concentrations of 0.25 ppm for 96 hrs produced little or no effect on molting but many larvae died within 48 hrs after removal to clean water. The 96 hr LC50 (concentration producing 50% mortality) for coonstripe shrimp molting larvae was 0.96 ppm but dropped to 0.24 ppm 48 hrs after removal to uncontaminated water, suggesting that the standard 96 hr biobassay is not long enough to determine the sensitivities of shrimp larvae to oils.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Physiological Effects					
Pink Shrimp (Pandalus borealis)	Rice et al., 1976	bioassays	Cook Inlet crude oil	water soluble fraction of Cook Inlet crude oil	Pink shrimp accumulate naphthalenes from the water soluble fraction of Cook Inlet crude in seawater. Accumulations in tissue were reported up to 260 times background levels. Depuration in shrimp returned to clean water was slow and took several weeks.
SALMONIDS					
Acute/Toxic Effects					
Pink Salmon fry (Oncorhynchus gorbuscha)	Rice, 1973	bioassay-acute toxicity effects	Prudhoe Bay crude oil - water soluble fraction	.75 mg-497 mg oil/liter of seawater	Observed 96 hr TLM levels for pink salmon fry were 213 mg oil/liter in June, and 110 mg/liter in August. Fish exhibited dramatic seasonal differences in sensitivity to oil pollution. Older fry were more susceptible to oil toxicity than younger fry and were more sensitive in their detection and avoidance of oil. Older fry in seawater avoided oil concentrations as low as 1.6 mg of oil/liter of water.
Juvenile Coho (Oncorhynchus kisutch) and Sockeye Salmon (Oncorhynchus nerka)	Morrow, 1973	96 hr bioassay	Prudhoe Bay crude oil - water soluble fraction	500 ppm - 3500 ppm in seawater	500 ppm - 3500 ppm of crude oil produced up to 100% mortalities in juvenile coho and sockeye salmon. Stress behavior began within 45 minutes of formation of an oil slick. Mortality rates were directly related to oil concentration and inversely related to temperature.
Eggs, alevins, and fry of Pink Salmon (Oncorhynchus gorbuscha)	Rice et al., 1975	96 hr bioassay	Prudhoe Bay crude oil (mechanical mixtures of oil and water)	.075 ml - 4 ml oil/liter of fresh and seawater	Standard 96 hr bioassays with "total" oil solutions in freshwater and seawater determined differences in developing life stages of pink salmon (Oncorhynchus gorbuscha). Eggs were the most resistant and emergent fry (yolk sac absorbed) the most sensitive to acute 4-day exposures. In fresh water, the 96 hr TLM of fry was 12 ppm. In seawater it was 6 ppm.
Pink Salmon fry (Oncorhynchus gorbuscha)	Rice et al., 1976	96 hr bioassay	Cook Inlet crude, No. 2 fuel oil, and Prudhoe Bay crude (oil-water dispersions, and water soluble fraction)		Acute toxicity of the water soluble fractions of Prudhoe Bay and Cook Inlet crude oil to pink salmon fry was 1.41 ppm and 2.92 ppm respectively. The 96 hr TLM for No. 2 fuel oil was 0.81 ppm.
Dolly Varden (Salvelinus malma) Chinook Salmon (Oncorhynchus tshawytscha)	Moles et al., 1979	bioassay 96 hr TLM	Prudhoe Bay crude oil	water soluble fraction of Prudhoe Bay crude oil and benzene	Salmonids were consistently the most sensitive of all species tested while three-spined sticklebacks were consistently the most tolerant. The 96 hr TLM for Dolly Varden was 2.75 mg/l total crude oil aromatics and 11.96 ul/l for benzene.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Coho Salmon (*Oncorhynchus kisutch*) Sockeye Salmon (*Oncorhynchus nerka*) Arctic Grayling (*Thymallus arcticus*) Arctic Char (*Salvelinus alpinus*) Slimy Sculpin (*Cottus cognatus*) Three-spined Stickleback (*Gasterosteus aculeatua*)					The 96 hr TLM for sticklebacks were 10.45 mg/l total crude oil aromatics and 24.83 ul/l for benzene. The sensitivities of pink salmon and coho salmon to benzene increased sharply during development from egg to fry. The egg stage was the least sensitive to benzene (96 hr TLM = 339 ul/l for pink salmon and 542 ul/l for coho salmon), the alevin stages were moderately sensitive, and the emergent stage was the most sensitive (96 hrTLM = 5.28 ul/l for pink salmon and 9.8 ul/liter for coho). For crude oil the 96 hr TLM for eggs were greater than 12 mg/l. Emergent fry were sensitive to Prudhoe Bay crude oil, with a 96 hr TLM of 8 mg/l for both species.
Dolly Varden smolt (*Salvelinus malma*)	Rice et al., 1976	static bioassay	Cook Inlet crude and and No. 2 fuel oil	water soluble fractions of oils-measured as ppm by IR method	96 hr TLM's for Dolly Varden were 2.28 and 2.93 ppm for Cook Inlet crude and Nc. 2 Fuel oil respectively.
Physiological Effects					
Rainbow Trout (*Salmo gairdnerii*)	Hawkes, 1976	bioassay	Prudhoe Bay crude oil	sublethal concentrations in ppm range	Rainbow trout which were exposed to water soluble fractions of Prudhoe Bay crude oil showed the following effects: (a) skin mucus release and erosion of upper dermal layers, (b) gill mucus release, lesions, cellular and subcellular damage, (c) liver damage, (d) increase in lens thickness causing myopia. These debilitating factors increase the chances for infection, predation and disease and decrease the fishes' chance for survival.
Coho Salmon (*Oncorhynchus kisutch*)	Roubal et al., 1976	bioassay	water soluble fractions of aromatic hydrocarbons		Significant levels of metabolites were found in the brain, kidney, muscle and gall bladder of coho salmon which had been exposed to benzene, naphthalene and anthracene. This may indicate areas of detoxification, and possible sources of secondary infections, contaminants, etc.
Alevins and fry of Pink Salmon (*Oncorhynchus gorbuscha*)	Rice et al., 1975	96 hr bioassay	Prudhoe Bay crude oil (mechanical mixture of oil and water)	.075 ml - 4 ml oil/liter of fresh and seawater	Three life stages of alevins were exposed to 10 day sublethal exposures of the water soluble fraction of Prudhoe Bay crude oil. Growth was most severely affected in alevins exposed during later developmental stages. Decreased growth was observed in fry after 10-day exposures at the lowest dose tested (.075 ml oil/liter). Reduction in size from exposure could have a detrimental effect on the survival of wild fry.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Pink Salmon fry (Oncorhynchus gorbuscha)	Rice et al., 1976	bioassay - uptake and depuration	Cook Inlet crude oil - water soluble	sublethal	Pink salmon fry which were exposed to the water soluble fractions of Cook Inlet crude oil accumulated naphthalenes in gill, gut, and muscle tissue. Investigators feel gill tissue is the most probable route of entry. Pink salmon are able to concentrate naphthalenes up to 480 times background levels. Pink salmon fry are able to actively depurate naphthalenes.
King Salmon fry (Oncorhynchus tshawytscha)	Brockson and Bailey, 1973	bioassay - respiratory effects	benzene fraction	5-10 ppm benzene	Respiratory rate was increased during the early (24-48 hr) period of exposure to both 4 and 10 ppm of benzene. After longer periods, respiration returned to near control levels.
Pink Salmon fry (Oncorhynchus gorbuscha)	Rice and Karinen, 1976	bioassay	Cook Inlet crude oil	sublethal	Respiratory rates in pink salmon fry increased significantly during exposures to water soluble fractions of Cook Inlet crude oil as low as 30 percent of 96 hr TLM value.
Pink Salmon fry (Oncorhynchus gorbuscha)	Thomas and Rice, 1975	toxicity - respiratory effects	Prudhoe Bay crude	2.83 and 3.46 ppm	Opercular rates increased significantly for as long as 9 to 12 hrs after exposure to sublethal concentrations of the water-soluble fractions of Prudhoe Bay crude oil. Observed changes occurred at aproximately 20% of the 96 hr LC50.
Pink Salmon fry (Oncorhynchus gorbuscha)	Rice et al., 1977	toxicity effects	WSF Cook Inlet and Prudhoe Bay crude and No. 2 fuel oil	sublethal	Breathing and coughing rates increased in proportion to oil concentrations. Significant responses were detected at about 30% of the 96 hr TLM. Breathing and coughing rates remained above normal during exposure for 72 hrs. Increased oxygen consumption was observed in fish exposed to oil concentrations that were 50% of a 96 hr TLM.
Coho Salmon (Oncorhynchus kisutch)	Malins et al., 1977	spill	diesel fuel	unknown	A diesel fuel spill blinded coho salmon located in rearing pens adjacent to the spill. Changes in the eyes included hydration and cloudiness.
Rainbow Trout (Salmo gairdneri)	Krishnaswami & Kupchanko, 1969	static bioassay and field observation	petroleum refinery effluent	sublethal	Rainbow trout exposed 24 hrs to refinery waste dilutions with a threshold odor number of .25 acquired an oily taste. Fish (trout) kept in cages in the river 15 mi (24 km) below refinery wastewater discharge point acquired an oily taste with river water odor levels of at least 1.0.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Coho Salmon (Oncorhyncus kisutch) Starry Flounder (Platichthys stellatus)	Roubal et al., 1978	flow through bioassay	WSF Prudhoe Bay crude	0.9 + 0.1 ppm WSF Prudhoe Bay crude	Coho salmon and starry flounder exposed to 0.9 ppm of a WSF of Prudhoe Bay crude oil, bioconcentrated low molecular weight aromatic hydrocarbons up to 1700 times the concentration in the water. Generally, starry flounder accumulated the greatest amounts. Alkylated aromatic hydrocarbons accumulated in tissues to a greater degree than unsubstituted derivatives, and accumulations of substituted benzenes and naphthalenes in muscles increased in relation to the degree of alkylation. Complex mixtures of aromatic hydrocarbons were found in gills and liver of starry flounder. Accumulated hydrocarbons were retained in starry flounder muscle for a longer period than in coho salmon tissue after removal to clean water.
Behavioral Effects					
Pink Salmon (Oncorhynchus gorbuscha)	Rice, 1973	bioassay avoidance tests	Prudhoe Bay crude oil - water soluble fraction	.75 mg - 16.0 mg oil/liter. Used water soluble fraction only	Pink salmon fry showed clear avoidance responses to oil concentration of 16.0 and 1.6 mg oil/liter. Pollution avoidance in Atlantic salmon is well documented. Avoidance could have an adverse impact on salmon populations by changing migration during critical periods such as fry outmigration or return of adults to spawning streams.
Juvenile Coho (Oncorhynchus kisutch) and Sockeye Salmon (Oncorhynchus nerka)	Morrow, 1973	96 hr bioassay	Prudhoe Bay crude (surface oil slick in aerated tank)		Change was observed in behavior of salmon under oil film. Within 2 to 4 hrs, the fry took up a position at the water oil interface, with their dorsal and caudal fins touching the oil. After 12 to 24 hrs exposure the less resistant individuals lost equilibrium and began swimming vertically. Most animals died shortly after becoming vertical. Animals exposed to crude oil showed abnormal values for blood pH, K+, and Cl-. In conjunction with observed behavioral abnormalities, this suggests very strongly that the chemical CO_2 and HCO_3- balance had been upset.
Rainbow Trout (Salmo gairdneri) Atlantic Salmon (Salmo salar)	Sprague and Drury, 1969	bioassay	phenol	.001 ppm - 10 ppm	Avoidance reactions were inconsistent even at lethal levels. Fish showed no signs of detection even at lethal phenol concentrations.
Atlantic Salmon (Salmo salar)	Rice, 1973	avoidance	copper and zinc pollution	sublethal	Although highly motivated by their instinct to migrate upstream, when Atlantic salmon reached a sublethal concentration of copper and zinc pollution in the Miramichi River, they aborted their upstream migration and returned downstream.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Coho Salmon (*Oncorhynchus kisutch*)	Malins et al., 1978	bioassay toxicity effects	Prudhoe Bay crude oil and selected aromatic hydrocarbons and heavy metals	varied	500 - 1000 ppb - a model mixture of aromatic hydrocarbons representative of the SWSF (salt-water soluble fraction) of PBCO, when introduced in the home stream inhibited upstream spawning migration of salmon in the early part of the run. 1000 - 2000 ppb - resulted in a delay of 2 days in the timing of return to the home stream - this delay is a conservative estimate. 2000 - 3000 ppb - this concentration of hydrocarbons in home stream water caused inhibition in upstream spawning migration of the run.
OTHER FISH					
Acute/Toxic Effects					
Cod (*Gadus* sp.)	Kuhnhold, 1972	bioassay	Venezuelan and Libyan crude oil	.5 gm oil/liter of water	100% mortality of eggs occurred in 3 and 6 days with Venezuelan and Libyan crude respectively. Controls developed normally. Larvae which hatch from eggs previously exposed to oil are usually deformed.
Herring larvae (*Clupea harengus*)	Rice et al., 1976	bioassay (96 hr TLM)	Cook Inlet crude oil	water soluble fraction	3 ppm of the water soluble fraction of Cook Inlet crude oil was sufficient to kill herring larvae within 96 hrs.
Herring larvae (*Clupea harengus*)	Cameron and Smith, 1980	bioassay	Prudhoe Bay crude oil	water soluble fraction	Eggs exposed to the water soluble fraction of PBCO produced larvae with no signs of outward gross abnormalities. However, electron microscopy revealed inter and intracellular spaces in brain and muscle tissues of exposed organisms but not in those of controls.
Herring (*Clupea harengus*) Lemon Sole (*Microstomus kitt*)	Wilson, 1976	100 hr bioassay	oil dispersants, Atlas, Basol AD6, BP1002, Corexit 7664, D-tar, Finasol ESK, Houghtoslov, Penetone 861, Slix	.5 ppm - 400 ppm	The LC50 values of 8 dispersants ranged from 4 to 35 ppm. The value for Corexit 7664 was 400 ppm. The difference in toxicity was associated with the composition of the dispersants and the percentage of aromatic hydrocarbons.
Herring (*Clupea harengus*)	Zitko and Tibbo, 1971	spill in Nova Scotia	"intermediate oil" with large concentrations of aromatic hydrocarbons	marine spill	Spill caused extensive kill of herring in 1969.
Selected Alaskan species of marine fish and invertebrates	Rice et al., 1979	static bioassay 96 hr TLM	Cook Inlet crude and No. 2 fuel oil	water soluble fractions 1-11.72 mg/l total aromatic hydrocarbons measured by gas chromotography and infra-red	Pelagic organisms were the most sensitive to oil, but may not be the most vulnerable. Pelagic organisms are mobile and can avoid a spill in most areas. Although benthic and intertidal species were more tolerant to short term exposure, the potential for high concentrations of toxic fractions occurring during ex-

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
				spectrophotometry	posure in their environment is greater because of mixing and entrainment of the oil in the shallow nearshore waters. Furthermore, habitats of benthic and intertidal species may be particularly susceptible to physical oil contamination.
Saffron Cod (<u>Eleginus gracillis</u>)	Rice et al., 1976	static bioassay	Cook Inlet crude and No. 2 fuel oil	water soluble fractions of oils measured as ppm by IR method	96 hr TLM's for saffron cod were 2.28 and 2.93 ppm for Cook Inlet crude and No. 2 fuel oil respectively.
Cod and Pollock (<u>Gadus morhua</u> and <u>Pollachius virens</u>)	Longwell, 1977	spill	80% #6 fuel oil 20% #2 fuel oil	unknown	Over 1/2 of the cod and pollock eggs collected near the <u>Argo Merchant</u> spill were contaminated by adhering tar and oil droplets. A significant number of the eggs collected were either dead (up to 46%) or contained grossly malformed embryos (18%). Spawning had just occurred.
Sand Lance (<u>Ammodytes spp.</u>)	Longwell, 1977	spill	80% #6 fuel oil 20% #2 fuel oil	unknown	Larvae of sand lance were sampled in the area of the <u>Argo Merchant</u> spill. The abundance of larvae decreased sharply at the two stations within the area of the thick slick.
Surf Smelt embryos (<u>Hypomesus pretiosus</u>)	NWAFC - monthly report, July 1980	Histopathological observation	saltwater soluble fraction (SWSF) of weathered Cook Inlet crude oil (CICO)	170-231 ppb oil/ 45-63 hrs.	Microscopic examination of 21 and 27 day old embryos exposed to 170 or 231 ppb CICO revealed abnormal or necrotic cells in brain and eye tissues. Large amounts of lysosomal enzymes were also present, indicating cellular degradation. Retinal receptors were damaged, with microscopic lesions located in the midregion of the receptor cell. A reduced hatching success was also noted in smelt after 177 hours of exposure to 231 ppb CICO (7.6% successful hatching) and 170 ppb CICO (12.1% successful hatching, compared to the control group (51.6% successful hatching).
<u>Physiological Effects</u>					
Eggs and larvae of Herring (<u>Clupea harengus</u>) Sole (<u>Microstomus kitt</u>)	Wilson, 1976	bioassay	oil dispersant	5-10 ppm	Oil dispersants at levels from 5-10 ppm caused abnormalities in developing herring, sole and plaice eggs and larvae.
Herring eggs and larvae (<u>Clupea harengus</u>)	Struhsaker et al., 1974	bioassay 48-120 hr	benzene fraction	water soluble fraction	Considerable physiological stress was noted. Higher concentrations of benzene reduced the metabolic rate. Although eggs are relatively resistant and require a greater amount of exposure before mortality, exposure usually causes abnormalities whose effects are permanent and irreversible, eventually causing death. On the other hand, exposed larvae may sometimes partially recover.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
English Sole (Parophrys vetulus)	Malins et al., 1977	bioassay	Prudhoe Bay crude oil	water soluble fraction	English sole held on contaminated sediments for over 4 months had a higher frequency of liver abnormalities and weight loss than did control fish on uncontaminated sediment.
English Sole (Parophrys vetulus)	McCain, 1978	toxicity effects	Alaskan crude oil	0.2% oil/sediment	English sole exposed to oil contaminated sediments for 4 months gained weight slower, had a higher frequency of liver abnormalities, a higher incidence of parasitic infestation of the gills, and were less active than control fish.
Coho Salmon (Oncorhynchus kisutch) Starry Flounder (Ptatichthys stellatus)	Roubal et al., 1978	bioassays	water soluble fraction of Prudhoe Bay crude oil	0.9 $\pm$ 0.1 ppm WSF of PBCO in flowing seawater	Results indicate that demersal fish (starry flounder) may be more susceptible to petroleum contamination than pelagic fish (coho salmon). Demersal fish had a longer retention time of aromatic hydrocarbons in relation to a shorter exposure period. Water soluble aromatic hydrocarbons were readily accumulated in muscle, liver, and gills of starry flounder, and in muscle of coho salmon exposed to 1 ppm WSF of crude petroleum. Starry flounder were found to accumulate benzene fractions up to 11,000 times the exposure factor.
English Sole (Parophrys vetulus) Starry Flounder (Platichthys stellatus)	Malins, 1980	project summaries	varied	varied	It was reported that marine fish may readily bioaccumulate or biotransform aromatic hydrocarbons when exposed through the diet, water column, or sediment. The extent of accumulation differs in relation to such factors as species, hydrocarbon structure, route of administration and environmental conditions. During biotransformation, one intermediate conversion product has been identified as an arene oxide which is known to cause lesions in the tissues of some mammals.
Saurel and Mackerel (spp. unknown)	Nitta, 1970	unknown	varied hydrocarbon fractions from Yokkaichi Harbour, Japan	0.01 ppm - 0.05 ppm oil	It was found that oil concentrations as low as 0.01 ppm were sufficient to impart an odor in fish. Saurel kept in seawater containing 0.01 ppm of oil took on a slight odor in 24 hours. Mackerel similarly acquired a slight odor after being placed in seawater containing 0.05 ppm oil.
Sea Mullet (Mugil sp.)	Grant, 1969	taste	kerosene	unknown	Kerosene tainting in sea mullet was reported near Brisbane, Australia where fishermen reported losses of as much as 78 short tons in one area.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Rainbow Trout (Salmo gairdneri) Starry Flounder (Platichthys stellatus) Coho Salmon (Oncorhynchus kisutch) English Sole (Parophyrus vetulus) Rock Sole (Lepidopsetta bilineata)	Malins et al., 1978	bioassays toxicity effects	Prudhoe Bay crude oil and selected aromatic hydrocarbons and heavy metals	varied	Morphology: In fish exposed to high levels of petroleum, eye lenses hydrate and may eventually produce cataracts, resulting in reduced vision or blindness. Liver tissue reflects exposure to contaminants in both its biochemistry and morphology. Changes involve alterations in glycogen or lipid deposits and proliferation of the endoplasmic reticulum in flatfish exposed to petroleum-contaminated sediment and trout exposed to PBCO. Chemistry: Within a few hours of naphthalene exposure, significant concentrations of both naphthalenes and their metabolites were present in the skin of coho salmon, starry flounder and rainbow trout. There is a tendency to preferentially retain metabolic products of hydrocarbons. Starry flounders demonstrated a propensity to accumulate and bioconcentrate hydrocarbons from the water column. It appears that skin and epidermal mucus play an important role in accumulation, discharge, and retention of hydrocarbons and their metabolites in fish. Pathology: Exposure of English sole to crude oil contaminated sediments, within the range reported to occur as a result of oil spills, tended to have greater weight losses leading in some cases to emaciation and morbidity; and sole livers during the first month of exposure had a higher frequency of severe abnormalities than controls.
Behavioral Effects					
Herring larvae (Clupea harengus)	Rice et al., 1976	biossay-96 hr TLM	Cook Inlet crude oil	oil slick on surface	Herring larvae did not avoid an oil slick but would repeatedly swim up to the surface and touch it. They did not appear to be able to detect the slick. Larvae were eventually overcome by the oil and settled to the bottom.
Herring larvae (Clupea harengus)	Kuhnhold, 1972	bioassay	Venezuelan and Libyan crude oil	water soluble fraction	Larvae were unable to avoid contaminated water, especially when oil was present as a dispersion. Author believed chemoreceptors were blocked or destroyed. Larvae would have little chance of survival if they remained in the oil dispersion.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Behavioral Effects					
Herring larvae (*Clupea harengus*)	Rice et al., 1976	bioassay-96 hr TLM	Cook Inlet crude oil	oil slick on surface	Herring larvae did not avoid an oil slick but would repeatedly swim up to the surface and touch it. They did not appear to be able to detect the slick. Larvae were eventually overcome by the oil and settled to the bottom.
Herring larvae (*Clupea harengus*)	Kuhnhold, 1972	bioassay	Venezuelan and Libyan crude oil	water soluble fraction	Larvae were unable to avoid contaminated water, especially when oil was present as a dispersion. Author believed chemoreceptors were blocked or destroyed. Larvae would have little chance of survival if they remained in the oil dispersion.
English Sole (*Parophrys vetulus*)	NWAFC monthly report November, 1979	flow through biossays	unknown	unknown	Results of these experiments indicate that high levels of oil incorporated in sediment were not avoided by juvenile flatfish. In this manner bottom dwelling fish may be exposed to oil over long periods of time.
Teleost (Bony) Fish	NWAFC monthly report, June 1980	unknown	polynuclear aromatic hydrocarbons (2,6-dimethyl/naphthalene)	unknown	When exposed to varied concentrations of the specific PAH--2,6-dimethyl/naphthalene (2,6-DMN) - fish were observed swimming vertically and upside-down. In nature, such abberent behavior would invite predation.
CLAMS, MUSSELS AND SCALLOPS					
Acute/Toxic Effects					
Pink Scallop (*Chlamys rubida*)	Rice et al., 1976	bioassay-96 hr TLM	Prudhoe Bay crude, Cook Inlet crude, and No. 2 fuel oil	water soluble fraction .80-3.15 ppm	96 hr TLM for scallops was 2.07 ppm and 3.15 ppm for Prudhoe Bay and Cook Inlet crude oil respectively. 96 hr TLM for No. 2 fuel oil was .80 ppm. Scallops continued to die up to 4 weeks after exposure to the WSF of crude oil.
Cockles (*Clinocardium* sp.)	Lechner, 1970	oil spill observation	JP5 fuel oil	spill	.Thousands of dead and extremely weak cockles were found throughout spill area. Area was declared a health hazard and residents were advised not to eat the clams.
Razor Clams (*Siliqua* sp.)	Tegelberg, 1964	oil spill	fuel oil	spill	300,000 razor clams were killed in less than a week by a fuel oil spill.
Soft-Shelled Clam (*Mya arenaria*)	Dow and Hurst *in* Michael, 1977	observation	fuel oil	spill	157 metric tons of clams existed prior to a fuel oil spill. Mortality was observed immediately after the spill, and a decline in numbers occurred for the next three years. Twenty-five percent of the original population died within four months; 55% were dead 17 months later; and an 86% mortality figure was reported 3½ years later. Only 22 metric tons survived as of August 1974.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Mussel (*Mytilus californianus*)	Kanter, 1974	bioassay	crude oil	$1x10^3$ppm - $1x10^5$ppm	*Mytilus* succumbed faster and in higher numbers at oil concentrations of $1x10^5$ ppm than $1x10^3$ ppm and $1x10^4$ppm. Larger experimental animals exhibited significantly higher mortalities than their smaller counterparts. Mortality varied by season.
Soft-Shell Clam (*Mya arenaria*)	Thomas, 1976	observation of spill	Bunker C oil	unknown	Mortalities of the soft-shell clam (*Mya arenaria*) after the 1970 Chedabucto Bay spill ranged from 19% to 73% in the areas sampled. Many clams left their burrows as these filled with oil. The clams either died on the surface or were eaten by predators. Soon after, clams started to die within their burrows. Dead clams were visibly contaminated with oil, and mortalities were proportional to surface oil cover. In areas where the substrate had become contaminated with oil, chronic mortalities in the clam population continued 5 years after the spill.
Physiological Effects					
Soft-Shell Clam (*Mya arenaria*)	Stainken, 1976b	flow-through bioassay	No. 2 fuel oil	10, 50 and 100 ppm	Sub-acute oil exposure resulted in a depletion of glycogen and general leukocytosis which was particularly evident in the blood sinuses of the pallium and mantle membrane. There was also an increase in vacuolation of the diverticula, stomach and intestines. The increased vacuolation of oil-exposed clams may also represent inclusion and intracellular compartmentalization of hydrocarbons.
Soft-Shelled Clam (*Mya arenaria*)	Stainken, 1978	bioassay	No. 2 fuel oil	exposure to sub-acute oil-in-water concentrations - 10, 50, and 100 ppm for 28 days	Low levels of oil caused a marked elevation in respiratory rates while higher concentrations depressed respiration. As long as the oil or water-soluble fraction is present, the rates remain affected. This dose-response relationship is further evidenced by the accumulation of hydrocarbons. It is believed the higher concentration may have reduced the filtration activity of those clams below that of clams tested at lower concentrations.
Soft-Shelled Clam (*Mya arenaria*)	La Roche, 1973 *in* Menzel, 1979	unknown	unknown	unknown	The incidence of gonadal tumors was reported to be much higher in soft-shelled clams from areas subjected to oil contamination than from unpolluted areas.
Oyster (*Crassostrea gigas*) Mussel (*Mytilus edulis*) Spot Shrimp (*Pandalus platyceros*)	Malins et al., 1978	bioassays toxicity effects	Prudhoe Bay crude oil and selected aromatic hydrocarbons and heavy metals	varied	The presence of naphthalene at concentrations as low as 1 ppb reduced the viability of gametes and larvae of mussels and oysters. The metabolic system of the adult spot shrimp provides an effective detoxification mechanism; however, it also creates a wide range of metabolites and intermediate compounds that are available to higher trophic level organisms.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Mussel (*Mytilus edulis*)	Lee, 1972	bioassay	naphthalene toluene benzopyrene tetralin mineral oil heptadecane	varied	Hydrocarbons were found to be readily taken up by gill tissues. Toluene, naphthalene, and benzopyrene did not have a lethal effect at concentrations used (up to 1 mg per liter), however, it was suggested that these aromatic compounds may inhibit the filtering ability of mussels.
Mussel (*Mytilus edulis*)	Fossato and Canzonier, 1976	flow-through bioassay	diesel fuel	200-400 ug/liter	Mussels were exposed for as long as 41 days to diesel fuel absorbed on Kaolin particles. Hydrocarbons were accumulated in the tissues in excess of 1,000 times the exposure levels. After removal, mussels began to depurate but still retained significant fractions after 32 days.
Soft-Shelled Clam (*Mya arenaria*)	Gilfillan and Vandermeulen, 1978	observation and lab tissue analysis 6-7 yrs post-spill observations in Chedabucto Bay	Bunker C oil	unknown	All tissue and sediment samples examined from the original polluted site contained traces of oil. Clam tissues were found to contain up to 200 ug/g oil in tissue, and sediment samples 3800 ug/g oil in sediment. Oiled populations of clams differed from unoiled populations in lower total numbers with fewer mature adults, a 1-2 yr lag in tissue growth, a lower shell growth rate, and a reduced carbon flux with a lower assimilation rate.
Scallops and other Shellfish	Blumer et al., 1970	observations of Falmouth, Mass. oil spill	No. 2 fuel oil		Hydrocarbons ingested by shellfish became part of their lipid pool. Oil was incorporated in the adductor muscle of scallops.
Pink Scallops (*Chlamys rubida*)	Rice and Karinen, 1976	bioassay	Cook Inlet crude oil		Found that the growth rate of pink scallops may be reduced as the result of oil exposure.
Mussel (*Mytilus edulis*)	Blumer et al., 1971	No. 2 fuel oil, West Falmouth spill field observation	No. 2 fuel oil		Gonads of mussels failed to develop in affected areas.
Mussel (*Mytilus californianus*)	Kanter et al., 1971	bioassay	crude oil		Coal Oil Point mussels were more resistant to hydrocarbons than mussels from other areas, suggesting that chronic exposures may lead to selection for more tolerant forms.
Pink Scallops (*Chlamys rubida*)	Rice et al., 1976	bioassay (96 hr TLM)	Prudhoe Bay crude, Cook Inlet crude, and No. 2 fuel oil	0.80 - 3.15 ppm	Scallops accumulated significant paraffin concentrations. Scallops rapidly accumulated naphthalenes. Depuration was slow but steady. After 120 hrs certain fractions were still detectable.
Clams (*Prototheca staminea*) (*Macoma inquinata*) Sipunculid (*Phascolosoma agassizii*)	Anderson et al., 1978	bioassay	Prudhoe Bay crude, oil	600 ug/g oil in sediment for 40 days and 60 days	Detectable levels of hydrocarbons were present in two deposit feeding species, *Phascolosoma agassizii* and *Macoma inquinata*, but not in *Protothaca staminea*, a filter feeder. These results suggest that mode of feeding is a determinant factor in the availability of sediment-sorbed hydrocarbons to benthic animals.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
					Hydrocarbon levels were 1-3 ppm combined aliphatics and diaromatics.
					Hydrocarbon concentrations in tissue of P. agassizii and M. inquinata increased even further over 60 days. Both the aliphatic and diaromatic petroleum hydrocarbons on, or in, marine sediments are more readily taken up by detritivores than filter-feeders, however, the extent of accumulation was relatively low compared to initial sediment hydrocarbon concentrations.
Clams (Saxidomus giganteus and Mya arenaria) and Mussel (Mytilus edulis)	Mix et al., 1976	analysis of background hydrocarbon levels	carcinogenic, polycyclic aromatic hydrocarbons (benzo-a-pyrene)		Detectable levels of carcinogenic benzo-a-pyrenes were found in bivalves from 43 of 44 sampling sites. High levels were present in mussels collected from industrial dock areas. Significant levels were present in Mya arenaria collected near industrial docks.
Scallops (Pecten opercularis) Cockles (Cardium edule) Mussels (Mytilus edulis)	Swedmark, Granmo & Killberg, 1973	toxicity effects	oil pollution	sublethal	Scallops and mussels are considerably less tolerant to oil pollution than mussels. At sublethal concentrations the ability of the bivalves to close their shells was greatly impaired. Exposure to diesel oil illicited the most severe effects.
Oysters (Spp. unknown)	NAS, 1975	observation reports	chronic pollution brines and spills	500 ppm in sediments	Tainting of oysters in Louisiana oil fields is frequently reported and is generally associated with sediments containing high levels of petroleum hydrocarbons (500 ppm). Tainted oysters must be removed to unpolluted areas for several months to make them marketable.
Oysters (Crassostrea virginica)	Ehrhardt, 1972 Anderson, 1975	field observation	chronic pollution (ship channel)		Oysters collected at the mouth of Houston Ship Channel showed much higher concentrations of hydrocarbons than those collected across the bay, which were 237 and 2 ug/g respectively.
Behavioral Effects					
Soft-Shell Clam (Mya arenaria)	Stainken, 1977	bioassay	No. 2 fuel oil and Louisiana crude	oil water emulsion (sublethal)	With increased concentration of oil, clams increased mucus secretion and decreased tactile responses. General behavioral sequence: successively impaired activity, immobilization and death. Increased metabolic demands for mucus production and excretion and the disruption of normal physiological and biochemical processes occurred at much lower concentrations than the LC50 value indicates. LC50 values: Phenol 565 ppm; and No. 2 fuel oil 475 ppm.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Clam (Macoma baltica)	Taylor and Karinen, 1977	bioassay in situ experiment	Prudhoe Bay crude oil	0.234 and 0.367 ppm naphthalene equivalents	Water soluble fraction of oil and oil-treated sediment inhibited burrowing and caused clams to move to sediment surface where they would be vulnerable to predation or die from exposure.
Habitats					
Intertidal Habitat	Teal et al., 1978	gas chromatography/mass fragmentographic analysis	No. 2 fuel oil	spill	Naphthalenes with 0-3 alkyl/substitutions and phenanthrenes with 0-2 substitutions in surface sediments decreased in concentration over time. The more substituted aromatics decreased relatively less and in some cases actually increased in absolute concentration. Aromatics were incorporated below the upper 0-7 cm to a depth of 25 cm. Organisms living in the marsh were exposed to heavier molecular weight fuel oil aromatics for at least 6.5 years.
Salt Marsh	Hampson and Moul, 1978	observation	No. 2 fuel oil	spill	Marsh grass in the lower intertidal zone which was impacted by a No. 2 fuel oil spill has shown an inability to re-establish itself by either reseeding or rhizome growth. The associated sediments show a correspondingly high concentration of petroleum hydrocarbons impregnated in the peat substrate. Erosion rates were 24 times greater in the affected site than the control. Microscopic algae were collected and those present were considered least sensitive to environmental changes. Interstitial fauna found in the study area exhibited an extremely reduced number of individuals and species.
Salt Marsh	NORCOR Engineering and Research Ltd., 1975	spill	Norman Wells and Atkinson Point crude oils	40-50 liters	Controlled spills of 40 to 50 liters, with fresh and weathered Norman Wells crude oil in an uncontaminated salt marsh, produced extensive vegetation kills. Only marsh plants above water line at the time of oiling were affected by the spill.
Ice	NORCOR Engineering and Research Ltd., 1975	spills	Norman Wells and Swan Hills crude oils	varied	When oil is released in the water column it rises toward the surface in a conical shaped plume. The oil tends to be unstable and breaks into small spherical particles of about 1 cm in diameter or less. On striking the underside of the ice, the oil radiates outward progressively filling depressions in the sheet. Within a matter of hours of the oil coming in contact with the ice a lip forms around the lens, preventing horizontal movement. During the depth of winter, a new layer of ice forms beneath the oil within several days. Once entrapped, the oil is stabilized until spring. The properties of the oil remain unchanged and there is little evidence of weathering or degradation.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
					Throughout the winter, oil only penetrates 5 to 10 cm into the loose skeletal layer. As the sheet begins to warm in the spring activity intensifies in the brine channels and the oil begins to migrate upward. The rate of migration increases with the level of solar radiation and ambient air temperature. Oil released in late April under 150 cm of ice was detected on the surface within an hour. On reaching the ice surface the oil saturates the snow cover and substantially reduces the albedo (reflectant property). This causes an increase in the level of absorbed solar radiation which accelerates the process. Oiled melt pools quickly develop. The albedo of an oil film on water is about one quarter that of oiled snow, consequently the melt is further accelerated. Oil is splashed on the surrounding snow by wind and wave action and the pools gradually enlarge until interconnected. New oil is continually being released until the melt reaches the initial level of the oil lens. Once melt holes develop and surface drainage patterns are established the sheet rapidly deteriorates. Depending on the nature and location of the sheet, oiled areas are likely to be free of ice between one and three weeks earlier than surrounding ice.
Ice	Stringer and Weller, 1980	literature summary of existing oil/ice data	varied	experimental spills	Equilibrium thickness of crude oil can be expected to be between 0.5-1 cm (Schultz, 1980). Results indicate (Cox and Schultz, 1980) that a relatively large volume of oil can be spread beneath the ice cover in the form of a 0.5-1 cm thick slick, and that for many months this slick can be immobile in the Beaufort Sea and perhaps other areas such as Kotzebue and Norton Sounds and some nearshore areas of the Chukchi Sea where under-ice current velocities are below the threshold required to cause the slick to move.
Arctic waters (August)	NOAA-USCG-Ministry for Greenland-joint report on USNS Potomic oil spill, 1979	spill	Bunker C fuel oil	107,000 gallons (380 tons)	Eleven days after the spill, flakes of oil were observed within the water column. These flakes were 5 to 10 mm on a side and about 1 mm thick. Either they were the residual of weathered lenses of once flaking oil, or more likely were the exfoliation of the skin of oil lenses. By 14 days, the oil was not noticeable from the air. The asphaltene content remained constant during the first 15 days of weathering.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
					During this same period, the lighter fractions were being preferentially removed, presumably by evaporation. If this was the case, then a relatively new sinking process is brought to light which can potentially cause rapid breakup of oil lenses and possibly sinking.
Pack Ice	C-Core, 1980	spill	Bunker C fuel oil	7000 tons	Oil was inaccessible to recovery due to entrainment in pack ice. The general trend was toward progressively smaller oil particles with mechanical grinding as a primary cause and "melt pocket" processes as a secondary factor. The pack ice served to contain oil offshore and light hydrocarbons tended to be enriched in the ice (with respect to the surrounding water).
Ice	Martin, 1980	Laboratory analysis of oil spilled in generated ice	Prudhoe Bay crude oil	200 ml	Laboratory experiments revealed that an important property relating to oil retention in growing ice is the existence of a "dead zone" or area of transition between solid and liquid behavior. In the study most oil ended up on the ice surface beyond the dead zone, with some oil droplets circulating in the grease ice ahead of the dead zone. In this manner oil may become entrapped in growing sea ice.
Algae (*Fucus vesiculosus*)	Notini, 1978	observation	No. 3 and No. 5 fuel oil	spill	Fuel oil released from the grounded tanker *Irini* drifted into a small bay in the Stockholm archipelago and wiped out nearly the entire community of littoral fauna which was present. In spite of the initial heavy degree of pollution and the almost total faunal mortality, considerable recolonization took place during the first summer after the spill. After four years, no significant evidence of lasting detrimental effects could be found.
Algae (*Fucus vesiculosus*)	Steele, 1977	bioassay JP-4 and JP-5 jet fuel oil	No. 2 fuel oil	0-2000 ppm	Small amounts of oil (200 ppb or less) cause an apparent stimulation of growth in juvenile plants; however, concentrations above this level produced increasingly deleterious effects on plant growth. In addition, when *Fucus* receptacles were placed in oil solutions during gamete release all germination ceased even when only minute quantities of oil were present.

Table 22

Scientific names	Common names	Habitat	°96 h TLm total aromatics
Fish			
1. Clupea pallasi	Pacific herring	pelagic	1.22 (0.88-1.56)
2. Salvelinus malma	Dolly Varden	pelagic	1.55 (1.30-1.80)
3. Oncorhynchus gorbuscha	pink salmon	pelagic	1.69 (1.47-1.83)
4. Theragra chalcogrammus	Walleye pollock	pelagic	1.73 (1.37-2.09)
5. Aulorhynchus flavidus	tubesnouts	pelagic	2.55 (2.06-3.03)
6. Myoxecephalus polyacanthocephalus	great sculpin	benthic	3.96 (3.52-4.40)
7. Platichthys stellatus	starry flounder	benthic	>5.34
8. Pholis laeta	crescent gunnel	intertidal	>11.72
9. Anoplarchus purpurescens	cockscomb prickleback	intertidal	>11.72
Crustaceans			
10. Crangon alaskensis	grass shrimp	subtidal	0.87 (0.83-0.91)
11. Pandalus goniurus	humpy shrimp	subtidal	1.79 (1.53-2.04)
12. Eualus suckleyi	kelp shrimp	subtidal	1.86 (1.66-2.07)
13. Pandalus borealis	pink shrimp	subtidal	4.94 (3.20-5.60)
14. Paralithodes camtschatica	king crab	benthic	3.69 (2.65-4.73)
15. Hemigrapsis nudus	purple shore crab	intertidal	8.45 (8.32-8.58)
16. Pagurus hirsuiticulus	hairy hermit crab	intertidal	>10.58
17. Orchomene pinguis	amphipod	planktonic	>7.98
18. Acanthomysis pseudomacropsis	mysid	planktonic	>9.02
Echinoderms			
19. Cucumaria vega	tarspot	intertidal	>6.84
20. Strongylocentrotus drobachiensis	green sea urchin	intertidal	>10.58
21. Leptasterias hexactis	six-armed starfish	intertidal	>10.58
22. Eupentacta quinquesimita	white cucumber	intertidal	>12.29
Molluscs			
23. Chlamys hericus	pink scallop	benthic	3.94 (3.52-4.39)
24. Mytilus edulis	blue mussel	intertidal	>8.97
25. Protothaca staminea	little neck clam	intertidal	>6.84
26. Collisella scutum	plate limpet	intertidal	8.18 (6.14-10.96)
27. Notoacmaea Pelta	shield limpet	intertidal	>8.46
28. Katharina tunicata	leather chiton	intertidal	>8.46
29. Tonicella lineata	lined chiton	intertidal	>8.46
30. Mopalia ciliata	ciliated chiton	intertidal	>8.46
31. Margarites pupillus	purple margarite	intertidal	>8.46
32. Littorina sitkana	sitka periwinkle	intertidal	>8.46
33. Thais lima	file periwinkle	intertidal	>8.46
34. Colus halli	Hall's colus	benthic	>8.98
35. Neptunea lyrata	ridged whelk	benthic	>10.58
Annelids			
36. Nereis vexillosa	mussel worm	intertidal	>10.58
37. Harmothoe imbricata	scale worm	intertidal	>10.58
Nemerteans			
38. Paranemertes peregrina	purple ribbon worm	intertidal	>10.58
39. Lineus vegetus	brown ribbon worm	intertidal	>10.58

Table 1. Sensitivities of 38 Alaskan marine species to Cook Inlet crude oil - 96-h TLm's are in mg/l of total aromatics determined by GC, with 95% confidence intervals in parentheses

Source: Rice et al., 1979

Table 23

Species	Cook Inlet Crude Oil 96-h TLm IR (mg/l)	Cook Inlet Crude Oil 96-h TLm Total Aromatics (mg/l)	Fuel Oil 96-h TLm IR (mg/l)	Fuel Oil 96-h TLm total Aromatics (mg/l)
Fish				
1. Oncorhynchus gorbuscha	1.50 (1.29-1.71)	1.69 (1.47-1.83)	0.54 (0.52-0.55)	0.97 (0.90-1.06)
2. Salvelinus malma	2.27 (1.94-2.60)	1.55 (1.30-1.80)	0.72 (0.67-0.78)	0.15 (0.14-0.16)
3. Myoxocephalus polyacanthocephalus	3.82 (3.51-4.13)	3.96 (3.52-4.40)	2.41 (2.15-2.67)	1.31 (1.25-1.37)
4. Platicthys stellatus	>4.69	>5.34	>1.72	>0.97
5. Pholis laeta	>5.89	>11.72	>1.72	>0.97
Crustaceans				
6. Orchomene pinguis	>7.40	>7.98	>0.48	>1.74
7. Acanthomysis pseudomacropsis	>9.12	>9.02	>0.45 (0.36-0.57)	2.31 (1.85-2.88)
8. Eualus suckleyi	3.94 (3.49-4.39)	1.86 (1.66-2.07)	0.59 (0.41-0.77)	1.10 (0.90-1.30)
9. Crangon alaskensis	2.19 (2.08-2.30)	0.87 (0.83-0.91)	0.43 (0.38-0.49)	0.36 (0.31-0.41)
10. Pagurus hirsuiticulus	>6.94	>10.58	>8.19	>3.36
11. Paralithodes camtschatica	4.70 (4.10-5.30)	3.69 (2.65-4.73)	0.81 (0.72-0.90)	1.02 (0.93-1.11)
Molluscs				
12. Collisella scutum	3.65 (2.62-5.08)	8.18 (6.14-10.96)	>8.19	>3.36
13. Chlamys hericus	5.20 (4.11-6.29)	3.94 (3.52-4.39)	>8.19	>3.36
14. Katharina tunicata	>8.72	>8.46	>8.19	>3.36
15. Mytilus edulis	>7.41	>8.98	>4.19	>1.25
16. Thais lima	>8.72	>8.46	>8.19	>3.36
Annelids				
17. Nereis vexillosa	>6.94	>10.58	>8.19	>3.36
Nemertean				
18. Paranemertes peregrina	>6.94	>10.58	>8.19	>3.36
Echinoderms				
19. Leptasterias hexactis	>6.94	>10.58	>8.19	>3.36

Table 2. 96-h Tlm's (with corresponding 95% confidence interval) for Alaskan Marine species sensitive to Cook inlet crude oil and No. 2 fuel oil-TLm's are reported in mg/l total aromatics as measured by gas chromatography and mg/l total hydrocarbons are measured by infra-red spectrophotometry

Source: Rice et al., 1979

Sensitivity of Areas and Recommended Mitigative Measures

Areas in the northern Bering Sea and Norton Sound were ranked as having a low, moderate, or high sensitivity to the impacts of oil pollution (see Map D). These designations were based on existing data, and were made after evaluating the following criteria:

1. The sensitivity of each fish and wildlife species or habitat to the effects of oil pollution.

2. The degree of sensitivity to oil pollution exhibited by each species during the various stages of its life history.

3. The time of year that these critical life history stages occur and the period during which each species would be most affected.

4. The location of habitats where critical life history stages occur.

5. The productivity of the habitat.

6. The uniqueness of the habitat.

7. The potential probability that a spill will impact sensitive biological resources or habitats as a result of natural physical processes such as circulation, wind, or tidal transport.

8. The species population numbers and the relative importance of the population.

9. The degree to which the impacts of oil pollution can be mitigated.

Specific considerations and assumptions that were made during ranking are as follows:

1. Coastal habitats which exhibit such features as longshore sediment transport into an area, floating debris (driftwood) commonly washed up on shore, or high oil retention shorelines, are particularly vulnerable to the impacts of oil pollution because such physical factors tend to increase the potential likelihood of an area being exposed to, or affected by, an oil spill.

2. Intertidal vegetation such as eelgrass and <u>Fucus</u> kelp beds, are vulnerable to oil pollution based on observations following oil spills which detail extensive losses due to physical coating.

3. All wetlands and tideflats are highly susceptible to all forms of oil pollution due to their high retention characteristics and slow degradation processes.

4. Benthic invertebrates (king crab, clams, starfish) and bottomfish (yellowfin sole, starry flounder, Arctic cod) are very sensitive to the toxic components of oil. However, it is unlikely that

oil pollution will significantly affect these species unless it is transported into juvenile rearing or settling areas, or is sedimented through adherence to suspended particulate matter within the water column.

5. Juvenile fish rearing and feeding areas are highly vulnerable to oil pollution as evidenced by toxicity studies.

6. Seabird populations, resting locations, and pelagic feeding areas are extremely sensitive to the effects of oil. This is due to the large amount of time that seabirds spend on the water; their discrete habitat requirements; their very large populational numbers in the Norton Sound-northern Bering Sea region; and the proven damaging effects that arise through direct physical contact with oil.

7. Waterfowl feeding, nesting, molting, and staging areas are considered highly vulnerable to oil pollution. This is due to the discrete characteristics of waterfowl habitat, the importance of habitats within the Norton Sound-northern Bering Sea region to various life history stages of waterfowl, their importance to large waterfowl populations during different times of the year, and because oil has been demonstrated to be lethal to a variety of waterfowl species.

8. Marine mammals are not considered to be particularly vulnerable to oil except under special conditions when they may be aggregated

(as in haulout areas), or when they are confined to a specific habitat and cannot escape being impacted by spilled oil (as with denning ringed seals). It is expected that marine mammals will in most cases avoid an area of obvious contamination.

9. Oil pollution may affect subsistence, commercial, and sport harvests of fish and wildlife resources through a reduction in the absolute number of animals harvested or which are available for harvest; through tainting or fouling of fish and wildlife species; or through physical fouling of harvest areas and equipment (boats, nets, crab pots, etc.).

10. The potential impacts of oil pollution on juvenile or larval marine organisms are extremely high. Because of the lack of systematic surveys and scientific data on early life history stages of marine species in the Norton Sound-northern Bering Sea region, larval and juvenile concentration areas have not been identified. However, the lack of identified concentration areas should not be construed to indicate that either these areas do not exist, or that these organisms are not extremely sensitive to oil pollution.

Sensitivity Designations and Mitigative Measures

LOW SENSITIVITY AREAS

The designation of low sensitivity applies to those areas which exhibit a high potential for cleanup, and/or include those species which would accrue only minor impacts when exposed to oil pollution. Oil exploration, development, production, and transportation may proceed in these areas with strict adherence to existing State and Federal regulations, except that oil spill response, containment, and cleanup capabilities should meet the standards set forth in moderate sensitivity areas.

MODERATE SENSITIVITY AREAS

The designation of moderate sensitivity applies to those areas in which there is a moderate to high probability that an oil spill would have significant adverse impacts upon sensitive or important biological resources. This designation includes: 1) areas in which the available information on net circulation indicates a high susceptibility to oil pollution; 2) areas in which relatively well substantiated circulation data indicates a moderate to high probability for transport and impingement of oil in sensitive or important areas; and 3) areas which exhibit a moderate potential for cleanup. Examples of moderate sensitivity areas include:

1. Areas receiving longshore sediment transport.
2. Areas where floating debris (driftwood) commonly washes up on shore.
3. Shorelines with high oil retention capabilities, such as saltmarshes and wet tundra.
4. King crab concentrations.
5. Herring nearshore feeding and rearing areas.
6. Capelin spawning and possible spawning areas.
7. Nearshore rearing areas for juvenile fish.

8. Sheefish and whitefish streams.

9. Sand lance concentration.

10. Waterfowl important staging areas.

11. Ringed seal important habitat.

12. Recurrent walrus haulouts.

13. Sea lion haulouts.

14. Subsistence harvest areas for belukha and bowhead whales, waterfowl, seabirds and eggs, seals, and walrus.

15. Commercial king crab harvest areas.

16. Subsistence clam and freshwater mussel areas.

Oil exploration, development, production, and transportation may proceed in areas of moderate sensitivity with strict adherence to State and Federal regulations, and by conforming to the following guidelines:

Prevention of Oil Spills

1. Exploratory Drilling - Because of effective U.S. Geological Survey regulations and enforcement, exploratory drilling operations on Federal OCS lands have a relatively good safety record and a low incidence of oil spills. Exploratory drilling operations in the northern Bering Sea - Norton Sound region would be acceptable with the following measures:

    a. USGS standards for both drilling operations and safety be adopted and enforced on both State and Federal lease tracts in the northern Bering Sea - Norton Sound region.

b. A second drilling rig with similar capabilities should be available in Alaskan waters to drill a relief well in the event of an uncontrolled flow of oil from a Norton Basin well due to a blowout or accident such as a rig fire. The rig requirement can be satisfied by an operational drilling platform in Alaskan waters, even if it is being used to drill another well, but must be capable of being on site and operational within 7 days after an uncontrolled flow has occurred.

c. Drilling platforms must be inspected to insure that they are capable of operating under the meteorological and geophysical conditions that are present in the northern Bering Sea and Norton Sound. Soil conditions at all drilling sites should be inspected and certified as being capable of supporting rig weights.

d. Only temporary drilling structures should be used during the exploration phase of oil development. After drilling, all structures should be removed and the site restored unless those structures will be used in the development of the field.

e. Because of severe winter ice conditions in Norton Sound and the northern Bering Sea, exploratory drilling from conventional jack-up rigs, drillships, and semi-submersible drilling rigs should be restricted to the ice free months of June through October.

f. Hazardous operations with high oil spill risk factors, such as testing and well completions, should be conducted only during periods when the ability to contain and cleanup a spill are maximized. This would typically be during calm open water periods.

Production Facilities

1. Production platforms in the northern Bering Sea and Norton Sound must be specifically designed and tested to operate safely under extreme conditions involving moving pack ice, maximum sustained wind speeds of 90 knots (100 mph), extreme wave heights of 32 meters (105 feet), and earthquakes of at least 6.5 on the Richter scale.

Onshore Facilities

1. Oil storage facilities should be sited a sufficient distance away from any open body of water so that even in the event of an uncontrolled spill, oil would not enter the water.

2. If facilities must be sited in wetlands or adjacent to a body of water, provisions must be made in design and construction to prevent the spread of hydrocarbons and to facilitate cleanup above and below ground. Such measures would require that oil storage and processing facilities be bermed and underlaid by natural or artificial impermeable barriers to prevent spilled oil from escaping the area and entering adjacent ground and surface waters.

3. Facilities which store large amounts of fuel should be sited away from sensitive fish and wildlife concentrations, such as seabird rookeries and wetlands.

4. Oil storage and processing facilities should not be located on geophysically unstable sites. This would include sites with unstable substrate, sites which could be affected by storm surges, and active fault zones.

5. Stationary fuel storage facilities for construction activities should not be placed within the floodplain of a fish stream, and vehicle refueling should not occur in these areas.

6. Effluent from refineries, oil treatment facilities, and petrochemical plants should be treated to reduce concentrations of aromatic hydrocarbons to below one ppm. Effluents should not contain any biologically significant amounts of heavy metals or carcinogenic compounds which might build up to toxic levels in sediment over the life of the project.

7. Hydrocarbon contaminated effluents should only be discharged into areas where there is sufficient water volume, strong tidal currents, and a rapid exchange of water to quickly dilute the effluent. Under no circumstances should they be discharged into any body of freshwater, estuary, or area exhibiting sluggish circulation.

8. Alternate methods to dispose of contaminated waste water, such as pumping it into reinjection wells or into impermeable formations underground, should be used whenever possible.

9. Alarm systems and security measures should be developed for all facilities handling oil to prevent spills caused by carelessness, vandalism, or sabotage.

Transportation

1. Pipelines

   a. Avoid construction of pipelines in geophysically active areas; i.e., across faultlines, in areas of current scour, in gas charged sediment areas, and areas prone to liquifaction.

   b. Submarine pipelines should be buried deep enough so that they will not be broken by ship anchors, gouging ice keels, or by fishing trawls.

   c. Submarine pipeline locations should be prominently marked on nautical charts and maps. Sonar targets should be placed on the pipeline at strategic intervals to aid in precise location.

d. Pipelines should be consolidated to the greatest extent possible in order to minimize habitat disturbance and risk.

e. Pipeline design and installation should reflect future developmental considerations such as increased volume during maximum production phases, and the ability to accomodate feeder pipelines from other developing fields.

f. Sensitive alarm systems and automatic shut-off valves should be required on all pipelines in order to minimize the amount of oil that would escape in the event of a pipeline rupture.

g. The number of stream crossings should be minimized. Attempt to make crossings downstream from sensitive habitats such as spawning areas. Uninterrupted movement and safe passage of fish should be provided for. Any artificial structure or any stream channel change that will restrict fish movement should be provided with an adequate fish passage structure or facility.

h. Pipeline routes should avoid areas of productive or critical benthic habitat such as larval king crab settling areas, larval shellfish release areas, salt marshes, and important clam beds.

i. Pipelines should be designed or sited in a manner that will not impede crab passage or migration.

2. Tanker docks and fueling facilities, which must be located in marine waters, should be designed to include:

   a. Automatic shut-off systems to stop the flow of fuel from storage areas in the event that a dock is damaged or destroyed.

   b. Redundant safety systems with exceptional safety factors incorporated in the oil transfer pipes, hoses, and other equipment, to eliminate the risk of failure and subsequent oil spillage.

   c. Redundant safety measures and additional crews should be required during operations with historically high spillage rates, such as the loading or unloading of tankers. These measures will help to prevent spills which often occur due to fatigue or carelessness.

3. Tankers

   a. Only U.S. Coast Guard inspected load on top or segregated ballast tankers which meet Coast Guard standards should be allowed to transport oil within the Norton Sound - northern Bering Sea region. Tankers destined for operation in this region should be specifically designed to withstand ice infested waters, with reinforced double hulls, multiple screws, and redundant steering systems.

b. Mandatory vessel traffic corridors and a vessel traffic control system should be implemented.

c. All tankers and other large vessels should be required to use certified pilots who are familiar with local hazards, weather, wind, wave, ice, and tidal conditions.

d. No discharge of ballast or bilge water should be permitted in the Bering Strait because of sensitive wildlife populations; or east of Cape Nome due to sluggish circulation regimes. Ballast water treatment facilities should be available at the tanker dock.

e. Tankers should be required to maintain a distance of at least 15 miles from established seabird colonies.

f. Ocean going tugs reinforced against ice should be available in Norton Sound to rescue any tanker which loses power or steerage before it runs aground.

g. At least one ice breaking vessel should be continually stationed in the Bering Sea.

h. Tanker routes in Norton Sound should only be established after conducting a careful scientific study and analysis to determine: 1) the safest routes through seasonal ice fields, storm paths, and hazards to navigation, and to 2) avoid sensitive fish and wildlife habitat which might be affected by a spill.

Oil Spill Containment and Cleanup

1. An effective oil spill containment and cleanup organization should be developed for this region before any drilling begins. This organization should have sufficient oil spill containment and cleanup equipment at its disposal to: 1) protect all identified critical habitats in Norton Sound, and 2) effectively contain and cleanup the maximum probable projected spill.

2. An effective oil spill response organization for the Norton Sound-northern Bering Sea region should have an oil spill contingency plan which would detail:

   a. Activities associated with oil field development, including offshore activities involving the handling or storage of oil or hazardous substances.

   b. Conditions under which the organization has a clear capability to contain and cleanup spilled oil; and conditions under which hazardous operations should be suspended.

c. Operational procedures, communications networks, detection and monitoring devices, equipment inventories, response times, and disposal sites.

d. Contingencies and equipment to handle all oceanographic and meteorological conditions which can be expected to occur in an area of drilling.

e. Provisions for under ice and broken ice containment and cleanup.

f. Locations of additional containment and cleanup equipment, the location of ports and airfields for transferring emergency equipment, the availability of transport and support vessels, and approximate response times to various spill sites.

g. Provisions for periodic revisions to the contingency plan, as necessary to accomodate operational changes and allow the incorporation of new technology.

3. Oil spill containment and cleanup equipment should be stationed at strategic points along the perimeter of Norton Sound and the Bering Strait in order to decrease the response time to any point within the lease area to a maximum of six hours after a spill has occurred.

4. Small scale containment equipment, sorbent material, and oil spill response training should be made available to coastal villages which might be impacted by a spill.

5. All tanker terminals, harbors, and ports which are utilized for oil related activities should have sufficient containment equipment available on site to handle the largest spill which might occur in those areas.

6. Anchor points for oil exclusion booms should be identified or placed near the mouths of all important fish streams, lagoons, bays, and estuaries.

7. Because existing oil spill containment and cleanup equipment is in many areas inadequate, satisfactory field demonstrations of equipment and organizational capabilities should be conducted prior to any approval of drilling permits, operation of facilities, or any shipment of oil by tankers. Where existing equipment is inadequate to effectively contain and clean up oil in broken ice, development of effective equipment for containment and cleanup of oil in ice should be made a requirement of permit approval.

8. Recognize the limited capabilities of existing equipment and the limited amount of equipment available. With present

operational and technical oil spill containment and cleanup it can be most effectively used to protect the most sensitive fish and wildlife concentrations or habitats from oil spills.

9. Dispersants - In the event that weather conditions or the location of a spill make mechanical containment or cleanup impossible, dispersants should be considered as an option to protect fish and wildlife resources under certain circumstances. However, there are several drawbacks to the use of dispersants.

The primary problem is that insufficient data is available on the effectiveness and toxicity of dispersants to make an objective decision regarding their use in Alaskan waters. Certain dispersants and dispersant-oil mixtures can be more toxic than the original parent oil, thereby precluding their use in most cases. The Environmental Protection Agency (EPA) has published a list of approved dispersants; however, the presence of a dispersant on this list only signifies EPA's acceptance of the method used to test the dispersant and is not necessarily an endorsement of its innocuous nature. The second problem is that, dependent upon type, dispersants will only work under certain temperatures and sea conditions. If these conditions do not exist during a spill then dispersants will not work. Third, there has to be a means of delivering the dispersants to the spill site. Vessels, fixed wing aircraft, and helicopters are all feasible, but weather and visability must meet minimum standards to be effective, especially in the case of airborne systems. Fourth, dispersants only remove the threat of mechanical damage (i.e., coating and abrasion) to fish, wildlife, and habitat, and may actually increase the amount of toxicity related damage resulting from a spill.

In light of the aforementioned problems, dispersants should only be considered as an option to protect fish and wildife resources or habitats under the following circumstances:

a. Only after consultation with the Departments of Fish and Game and Environmental Conservation. To effectively utilize dispersants, approval for their use, and the conditions under which they can be used will have to be determined in advance of any spill.

b. When mechanical means of oil spill containment and cleanup are not feasible.

c. When oil spill trajectories clearly indicate that the threat of physical damage and fish and wildlife mortalities at the projected impact site clearly exceed the toxic effects of using dispersants at the spill site or at some point along the spill trajectory.

d. Dispersants should only be used to protect sensitive species and habitats from the physical effects of oil spills and should never be used simply to remove visible components of oil pollution. Dispersants increase toxicity and solubility within the water column and may adversely affect larval marine organisms and fish if used improperly. Species sensitive to physical damage from oil spills include: seabirds, waterfowl, seal pups, intertidal spawning herring, and pelagic juvenile marine species. Sensitive habitats include: eelgrass, Fucus beds, salt marshes, stream deltas, and depositional shorelines.

e. Dispersants should only be used on large oil slicks in open water areas which present a definite threat to fish, wildlife, or sensitive habitat on shore. If a spill is far offshore and is breaking up, it should be allowed to dissipate naturally unless it can be contained or cleaned up by mechanical means.

f. Do not use dispersants in spawning areas during seasons when large concentrations of commercial or ecologically important fish or shellfish eggs or larvae are in the water column.

g. Do not use dispersants on spills of light hydrocarbon products such as gasoline or light diesel fuels. These products naturally dissipate rapidly and dispersants would increase environmental damage by distributing them in the water column. Use only on crude and bunker oils.

h. Only non-toxic dispersants, or low-toxicity dispersants with a very low application rate (one gallon of dispersant to 100 gallons of oil), should be used on Alaskan spills.

Monitoring

1. Ambient hydrocarbon levels should be recorded in the water column and sediments prior to any developmental activity or facility operation which will discharge hydrocarbons or other hazardous substances into the marine environment. Ambient levels should further be monitored regularly to insure that discharge standards are not exceeded.

2. Tissue samples of species which commonly occur and are harvested in an area of oil development should be obtained periodically to insure that hazardous bioaccumulations of hydrocarbons, heavy metals, or other hazardous substances do not occur.

HIGH SENSITIVITY AREAS

The designation of high sensitivity applies to habitats and species with a very high vulnerability to impact from oil pollution. Areas may additionally be rated high based upon their oil retention capabilities or because they are important areas of marine or freshwater harvest.

High sensitivity areas include:

1. Areas of first open water in spring

2. Eelgrass and *Fucus* kelp beds.

3. Wetlands, tideflats, estuaries, or lagoons.

4. Arctic char concentration areas.

5. Herring spawning and possible spawning areas.

6. Salmon streams and salmon fry and juvenile feeding or rearing areas.

7. Seabird colonies, concentrations at the base of colonies, and pelagic feeding areas.

8. Waterfowl and shorebird spring concentration areas.

9. Waterfowl nesting, molting, and major staging areas.

10. Seaduck wintering areas.

11. Emperor and snow geese molting and staging areas.

12. Swan nesting and use areas.

13. Sandhill crane use areas.

14. Shorebird important habitat and fall staging areas.

15. Ringed seal high density areas.

16. Spotted seal haulout and feeding areas.

17. Commercial and subsistence fishing areas.

18. Subsistence and sport fishing areas.

19. Subsistence fishing areas.

20. Subsistence king crab harvest area.

21. Commercial and subsistence herring harvest areas.

22. Subsistence winter herring harvest areas.

Operations, activities, structures, or facilities with a high probability of acute or chronic oil pollution should not occur or be located in high sensitivity areas.

TABLE 24 : MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND SPECIES, HABITATS OR HARVEST ACTIVITIES ARE MOST SENSITIVE TO OIL POLLUTION.

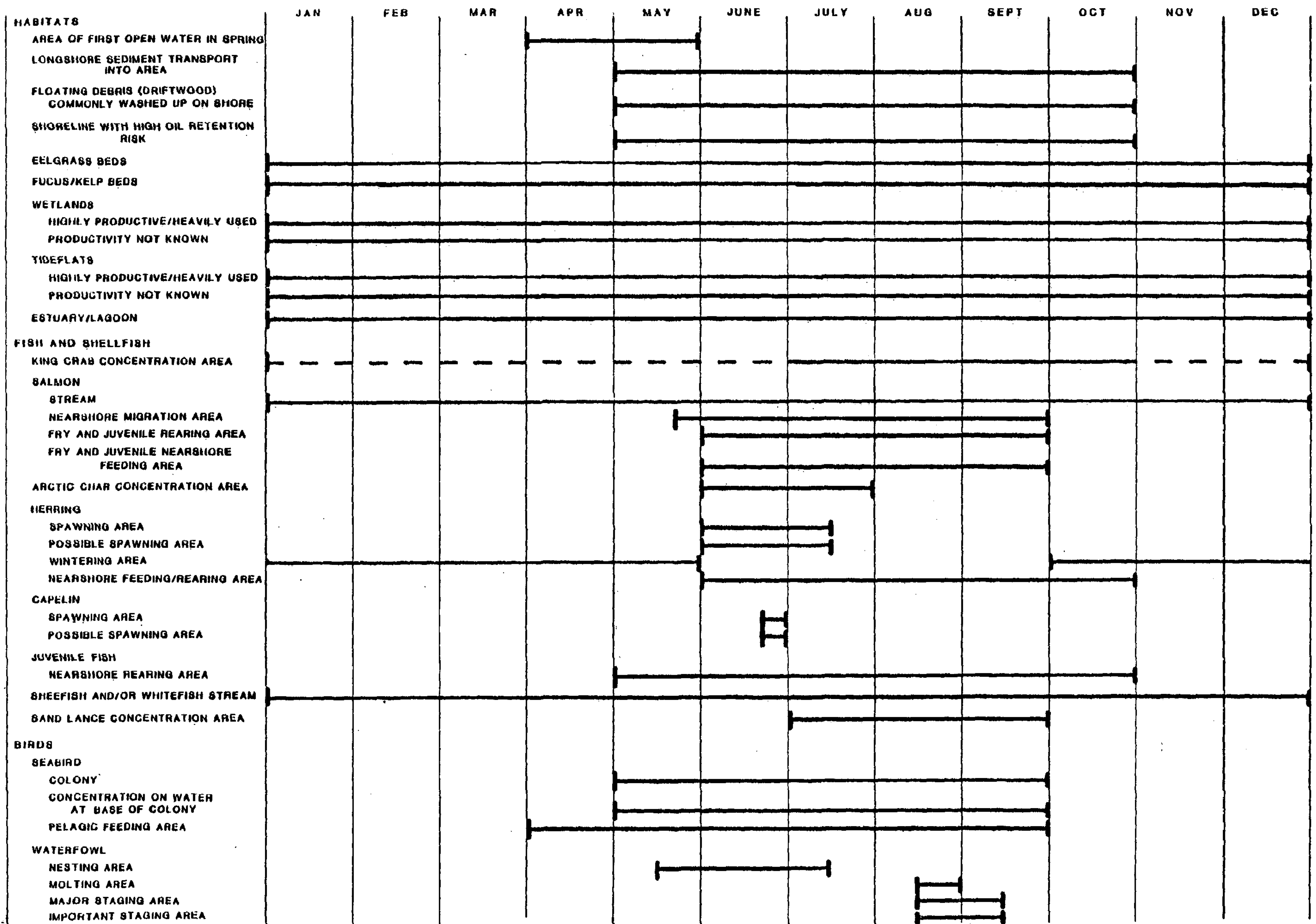
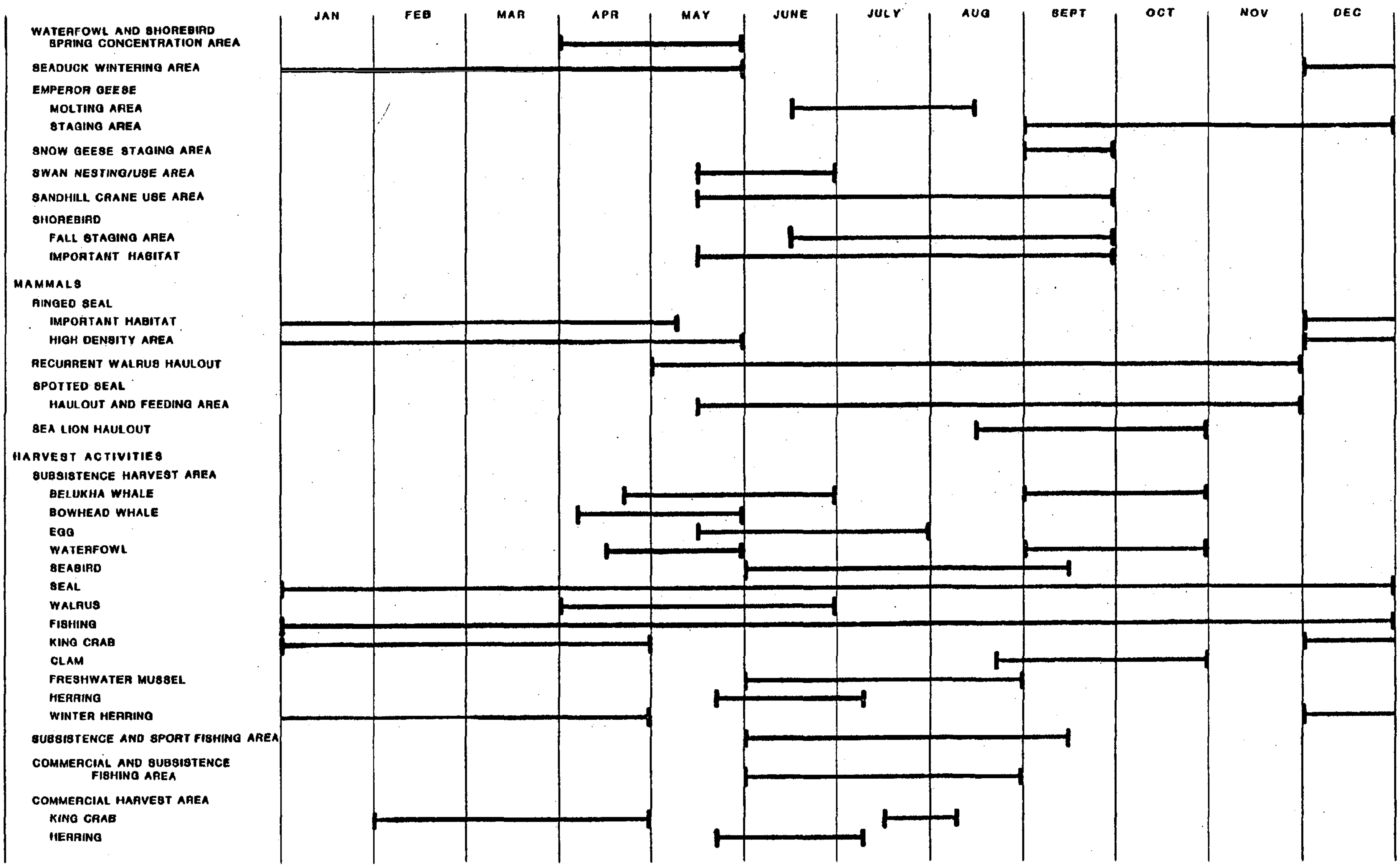


TABLE 24: (CONT.) MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND SPECIES, HABITATS OR HARVEST ACTIVITIES ARE MOST SENSITIVE TO OIL POLLUTION.



E

GRAVEL MINING & GRAVEL ISLANDS

DREDGING & FILLING

DREDGING AND FILLING, GRAVEL MINING, AND GRAVEL ISLANDS

Sources and Biological Effects

Dredging, the excavation of bottom materials, usually takes place during the development and production phases of petroleum development and is used to: 1) create and maintain navigational channels, turning basins and harbors for ships, 2) excavate pipeline ditches for the transportation of oil and gas between onshore and offshore facilities, and 3) obtain a source of material for fill or construction of onshore and offshore facilities (Clark, 1977; ASPO, 1978). Gravel mining may also occur during the exploration phase of oil and gas development if onshore facilities or gravel islands are required to support exploratory drilling. Onshore, construction in permafrost terrain necessitates significant quantities of gravel for foundation pads, roads, air strips, work pads and pipeline bedding. Offshore, gravel is required for the construction of artificial islands which are used as drilling platforms or tanker loading facilities. Filling includes the disposal of dredged material, the building of gravel pads for foundations and roads, building of gravel islands, and creation of new land in coastal areas.

All these activities, dredging and filling, gravel mining, and the construction of gravel islands, alter coastal habitats by changing aquatic habitats into terrestrial habitats, altering drainage patterns and stream channels, redistributing bottom sediments, and altering circulation patterns in bays and estuaries (Allen and Hardy, 1980; Moulton, 1980; Quigley, 1977). Effects on species occur as a direct result of the activity (burial by dredge disposal, entrainment in equipment, etc) or indirectly when habitats or water quality are altered.

Dredging

Two general types of dredges are commonly used in the United States; hydraulic dredges and mechanical dredges. About 99% of the dredging volume is accomplished by hydraulic dredges (Pequegnat et al., 1978). Hydraulic dredges (pipeline dredges, hopper dredges, and sidecaster dredges) mix sediments with water to form a slurry which is pumped to a discharge point. Mechanical dredges such as the bucket or dipper dredge are seldom used in projects involving large volumes of material but are valuable for working in small areas such as near docks or boat slips and for the cleanup of spills and contaminants. Ladder dredges (a mechanical dredge) are used only in the United States for mining operations although they are common components of European dredging fleets. Mechanical dredges are usually mounted on barges and move material mechanically with some type of bucket. The dredged material is usually transported by barges. Less water is incorporated into the material than occurs with hydraulic dredging and so less turbidity occurs (Allen and Hardy, 1980).

Dredging affects fish, wildlife, and aquatic plant resources in the coastal environment by 1) the physical destruction of benthic habitat, 2) altering water quality through the suspension of sediment which may have a high biological oxygen demand, 3) smothering benthic organisms when suspended silt and overburden are deposited on adjacent areas, 4) modifying water circulation patterns through the alteration of natural bottom contours and features, 5) modifying salinity concentrations when the flow or rate of input of freshwater to estuarine systems is disrupted, and 6) direct mortality of marine life as organisms are swept into dredging equipment. The effects of dredging may be short or long-term, depending upon the area dredged, the amount of material removed and the extent to which bottom contours and natural features are altered. Such alterations adversely affect plants and animals living in these habitats.

The most obvious result of dredging is the destruction of habitat. Submerged bottoms, coastal wetlands and tidelands may be destroyed, drained, or drastically altered by dredging (St. Amant, 1971). Benthic and epibenthic (animals living on the surface of the bottom substrate) organisms, such as clams, are destroyed as they are swept into dredging equipment. Mobile organisms are displaced or driven out of the area by dredging activities (Clark, 1977). Fish spawning areas may be destroyed directly through burial, or through disruption of the substrate (Morton, 1977).

Alteration of circulation patterns within bays or estuaries may displace planktonic organisms such as larval crab and shrimp to a less favorable environment. Changes in salinity and oxygen levels in bays and estuaries will seriously affect populations of organisms living in those areas (NERBC, 1976). Many estuarine plants and animals live near the limit of their tolerance ranges, and any additional dredging related stresses, such as increased sedimentation or decreased oxygen concentrations in the water, may exclude these organisms from the estuary. Large amounts of fresh water flowing into an estuarine system from tributary streams and wetlands create low salinity regions which are important nursery areas for juvenile fish and invertebrates. The variations in salinity which result from the seasonal discharge patterns of tributary streams appear essential in the life cycle of organisms which spawn inside the estuary (Odom, 1970). Dredging in stream mouths or in the nearshore area often modifies the flow of freshwater into the system and as a result changes both the extent and location of these low salinity areas. If affected estuarine organisms cannot tolerate the change in salinity level they will die or be forced to move to more suitable habitat.

Another environmental impact caused by dredging is the alteration of water quality due to the release of suspended sediments. The resuspension of bottom sediments causes the water to become turbid therefore limiting the amount of light entering the water column. When light penetration is reduced, the growth rates of phytoplankton are also reduced, limiting the amount of food available for other members of the food web including zooplankton, fish, birds, and marine mammals (Clark, 1977). Reduced plant growth also lowers oxygen levels in the water column.

The gills, which are the breathing apparatus of fish and other marine organisms, and the feeding mechanism of filter feeding animals such as clams, mussels, and sponges, can be clogged or abraded by suspended bottom particles (Clark, 1977). The effects of heavy loads of suspended sediments on filter feeding aquatic organisms include: abrasion of gill filaments, impaired respiration due to clogged gills, impaired feeding and excretory functions, and reduced growth and survival of larvae. If dredging operations cause the suspension of large quantities of silt, the productivity of local marine communities could be decreased. Any effects on marine communities can directly affect commercial, subsistence and sport fisheries which harvest these populations, or members of the higher trophic levels that prey on these organisms (Morton, 1977).

Larval stages of bivalve molluscs, such as Pacific oysters, quahog clams, American oysters, and European oysters, are also sensitive to natural sediments in the water column. Sedimentation interferes with shell formation, growth and survival and these species will not settle out or develop in areas with silty waters (Cardwell, et al., 1976).

O'Connor et al. (1976) found that in estuarine systems concentrations of suspended sediments such as those produced during dredging and disposal of dredged materials would be lethal to estuarine fish populations. The most lethal effects of suspended solids were found in 1) lower trophic level fish (anchovies and juvenile white perch), 2) juvenile fish, and 3) species with high oxygen requirements. In tests, juvenile dungeness crab, (*Cancer magister*), were adversely affected by suspended sediments in concentrations less than those produced by some dredging operations. Twenty-five (25) days exposure to concentrations of 1.8 and 4.3 g/l resulted in serious growth abnormalities, and prolongation of molt. At suspended sediment concentrations of 9.2 g/l and above, 50% to 85% of the crabs which started to molt died in the process. Ninty-two percent (92%) of all mortalities occurring during increased sediment levels were associated with molting. Researchers concluded that a one to three week exposure to concentrations of 2 g/l to 20 g/l of some harbor sediments would be lethal to most juvenile Cancer magister (Peddicord and McFarland, 1976).

Another adverse impact, the smothering of benthic (bottom) life, is caused by dredging. As the sediments suspended by dredging settle out and collect on the bottom, non-mobile plants and animals may be smothered. Sessile or attached organisms such as oysters, mussels, and barnacles, which cannot burrow up through the sediments, are killed directly by burial from discharge of dredging spoils (Morton, 1977). When sediments are anoxic (without oxygen) smaller animals are more vulnerable to burial because they are unable to reach the surface before they suffocate. Small crustaceans respond to oxygen depletion by increased ventilation, rapidly using up the available dissolved oxygen in the water (Saila et al., 1972 in Morton, 1977). Mobile organisms, such as fish, shrimp, and crabs usually abandon dredged areas (Clark, 1977).

Dredging for Pipeline Laying

The construction of offshore pipelines provides a good example of the effects dredging activities have on fish and wildlife resources and marine habitats. When oil and gas are discovered in commercial quantities, a pipeline must be laid to deliver these products from the offshore production platform to onshore facilities. Present Department of Interior administrative procedures require the burial of pipelines in water depths of less than 200 feet (60 meters) (NERBC, 1976). Plows, jets, and dredging are methods used to bury pipelines and, during the process of laying pipelines, benthic habitat is disrupted. Where impenetrable substrate is encountered, blasting may be required at the landfall (the point at which the pipeline comes onshore).

High pressure water jets are used to bury pipelines by blowing away the sediment underneath the line. The pipeline then settles into the trench where the sediment was displaced and is covered over by backfilling or by natural sediment transport processes. This dredging technique disturbs the bottom habitat and causes suspension of solid particles in the water column resulting in turbidity and the displacement or burial of benthic organisms. The impacts of turbidity on benthic organisms have been reported to occur 200 or more feet (60 meters) from the pipeline construction site (Clark and Terrell, 1978). When pipeline corridors are selected along bedrock, underwater blasting may be used to provide a suitable trench for the line. Overpressures from blasting may kill fish and other marine organisms in the vicinity of the line (NERBC, 1976). Long term damage from habitat disruption is more likely to occur in nearshore and onshore areas because of environmentally sensitive habitats such as estuaries and wetlands. Estuaries have rich supplies of nutrients that support dense populations of phytoplankton which are food for zooplankton, larval fishes, and benthic organisms (Gross, 1972 in Morton, 1977). Estuaries and wetlands are used by aquatic species as breeding grounds, nursery areas or home territories (Morton, 1977). Consequently, the position of a pipeline landfall is extremely important. Special construction procedures must be followed to protect the integrity of dunes, barrier islands, wetlands, estuaries, intertidal areas, and other sensitive areas at the marine-land interface (NERBC, 1976).

The primary impact of onshore pipeline construction is the destruction of vegetation and the associated changes in habitats and permafrost stability (NPRA Task Force, 1978; USGS, 1979). Pipelines crossing streams can impact fish habitat by disturbing the benthos and producing temporary or permanent blockage to fish and nutrient movements (USDI, 1972 and USDI, 1976 in NPRA Task Force, 1978). Sediments suspended by construction activities can cause adverse impacts on fish and their food sources. Turbid waters block light transmission which reduces the visual feeding range of fish and also decreases primary productivity, thereby limiting food sources for fish (Lynch et al., 1977). The direct effects of turbidity on adult fish may be less harmful than the effect of turbid waters on primary productivity and food organisms upon which fish depend for survival (Hesser et al., 1975). Saunders and Smith (1965) studied the effects of increased siltation on populations of trout in Ellerslie Brook on Prince Edward Island, Canada. Their study showed that the standing stock of trout was reduced because hiding places and spawning areas were silted over. Fine sediments affect juvenile fish by causing inflammation of the gill membranes and eventual death. Reports show that fry and fingerling trout reared in turbid water are more prone to bacterial infection of their gills (Lynch et al., 1977). Increased siltation in streams affects the quality of fish habitat by covering it with a uniform substrate, eliminating protective hiding places for fish, or by filling in pools where fish may overwinter. Fish spawning areas may be greatly impacted by siltation which buries the spawning beds and blocks intergravel flow by filling in the interstitial spaces between the gravel.

Exposed onshore pipelines have the potential of inhibiting or blocking movements of migratory animals such as moose and caribou (NPRA Task Force, 1978). Restriction of caribou movements by the Trans Alaska Pipeline System (TAPS) is well documented (Cameron & Whitten, 1976 and 1977).

Gravel Mining

Gravel requirements during oil and gas development in arctic and subarctic regions are high (see Table 25). Gravel to fulfill these requirements will be mined from offshore areas, coastal deposits, uplands, or from floodplains. Impacts in each of these areas will be different.

Impacts on fish and wildlife from gravel mining in marine areas will be similar to impacts occurring during dredging: Increased siltation in the water column, alteration of bottom sediments, changes in bottom topography with resultant changes in circulation patterns, and changes in benthic species abundance and diversity. Other impacts would result from the noise and disturbance caused by operation of dredging equipment and by barge traffic as the gravel is transported to areas where it is needed. In the Canadian Beaufort Sea, belukha whale migrations and distribution in nearshore feeding areas were affected by increases in barge traffic during the construction of offshore gravel islands (Fraker, 1977).

Gravel mining in upland habitats will lead to impacts on birds and mammals if mining is conducted during critical life history stages (such as raptor nesting or grizzly bear denning) or if mining leads to habitat

TABLE 25

SUMMARY OF GRAVEL REQUIREMENTS FOR VARIOUS PETROLEUM FACILITIES IN ARCTIC AND SUBARCTIC REGIONS 1/

Facility	Dimensions/Specifications	Gravel Requirements cubic meters	Gravel Requirements cubic yards
Pipeline work pad	1.5 meters (5 feet) thick; 20 meters (65 feet) wide	30,177/km	63,555/mile
Pipeline access road	1.5 meters (5 feet) thick; 8.5 meters (22 feet) wide	10,214/km	21,511/mile
Pipeline haul road	1.5 meters (5 feet) thick; 9 meters (30 feet) wide	13,928/km	29,333/mile
Airstrip (all weather)	1,523 x 40 meters (5,000 x 150 feet); 1.2 to 1.8 meters (4 to 6 feet) thick	84,955 - 126,159	110,000 - 165,000
Camp and drill pad (onshore exploratory well)	128 x 98 meters (420 x 320 feet), 1.27 hectares (3.1 acres)	26,760 - 38,230	35,000 - 50,000
Crude Oil Terminal			
Small-Medium (<250,000 b/d)	32 hectares (80 acres)	267,610 - 535,220	350,000 - 700,000
Large (500,000 b/d)	120 hectares (300 acres)	1,146,900 - 1,911,500	1,500,000 - 2,500,000
Very Large (>1,000,000 b/d)	202 hectares (500 acres)	1,835,040 - 3,440,700	2,400,000 - 4,500,000
LNG Plant			
Small-Medium (400 MMCFD)	25 hectares (60 acres)	214,088 - 420,530	280,000 - 550,000
Large (750-1,000 MMCFD)	100 hectares (250 acres)	917,520 - 1,529,200	1,200,000 - 2,000,000
Construction Support Base	16 - 30 hectares (40 - 75 acres)	152,920 - 382,300	200,000 - 500,000
Exploration Island	see Table 26		
Production Island	see Table 26		

1/ Hanley et al., 1980

alteration and lowers the usefulness of the area to species during a critical life history stage (such as wintering areas used by muskoxen or moose). Additional impacts from upland gravel mining will result from the transportation of gravel between the mining site and the construction site. Man made cuts, cuts in river banks and through rock knobs and ridges can cause slumping or gullying (USGS, 1979). Proliferation of roads can result in alteration of drainage patterns, ponding and channelization of runoff flows, permafrost degradation, blockage of fish passage in streams, increased siltation and runoff into streams, and blockage or deflection of wildlife migrations and vegetative changes in surrounding areas from dust clouds raised by passing vehicles (USGS, 1979).

Secondary impacts from upland gravel mining sites can also be expected. Quarry sites would leave scars along ridge crests and hilltops which would require erosion control to prevent soil flows, soil slumps and landslides. Water collecting in upland pit sites may generate thaw collapse of pit banks. Drainage from water-filled pits can result in gullying and siltation of downstream areas (USGS, 1979).

Removing gravel from coastal beaches can cause extensive erosional damage and shoreline changes at or adjacent to the mining area. Mining gravel from barrier island chains (or spits) can disrupt the stability of coastal bay-lagoon systems which are of prime importance to waterfowl and anadromous populations of whitefish and Arctic char. Although there may be some areas of littoral drift convergence and active deposition where coastal gravel mining could take place without disruption to wildlife habitat, most areas are sensitive (USGS, 1979).

Gravel removal in floodplains can result in significant impacts to fish and wildlife populations and long term alterations of important fish and wildlife habitats. Major effects of mining in floodplains include: The possibility of fish entrapment in pits or behind berms following periods of high water, diversion of stream channels, vegetation removal, and changes in stream hydrology. Removal of vegetated areas or banks of active stream channels, can destroy channel integrity and may allow water to spread over a larger area. Decreased water depth and velocity increases sedimentation rates and alters water temperature and disolved oxygen levels (Woodward-Clyde, 1980). Fish spawning and rearing areas may be lost or become less suitable and shallow water areas may block fish migrations.

Rundquist (1980) found that ratios between surface flow and subsurface flow were altered at several sites following gravel removal. At one site, stream flow entered the mined area and spread out through loose, uncompacted gravel resulting in a substantial reduction in surface flow during low water periods. Intergravel flow was still evident thirteen years after the site was worked. At another site surface flow ceased entirely for a period of two years (Rundquist, 1980). In portions of arctic rivers where stream width and depth have been increased by the gravel removal, declines in stream flow velocity could cause ice floes to gather. At the downstream end of the gravel removal area these floes could jam where the channel constricts back to the natural width. Ice jams could cause flooding in, and upstream from, the mined area and possible bed scour beneath the ice jam. Obstructions, such as dikes, left in the stream channel could also contribute to ice jamming (Rundquist, 1980). Reduced stream flow can also lead to <u>aufeis</u> formation. <u>Aufeis</u>

formation occurs in areas of decreased stream channel depths. In these shallow areas, the ice cover freezes to the bottom resulting in glaciation of flow over the top of the ice. As this flow continually freezes, an area of thick ice builds up. Aufeis formation diverts normal under ice and intergravular flow, and may dewater downstream fish spawning and overwintering areas. This area of thick ice (or aufeis) also remains longer in the spring than surrounding snow and ice and can block early spring fish migrations. Some aufeis remnants remain in place through the summer (Moulton, pers. comm.).

In-channel gravel mining can lead to increases in siltation with resulting mortality to early fish life stages. The deposition of sediments in fish spawning streams reduces the flow of water through the interstitial spaces in the gravel suffocating eggs, embryos, and alevins. Fine sediments affect juvenile fish by causing inflammation of the gill membranes, bacterial and fungal infections, and eventual death (Lynch et al., 1977). Siltation can also alter stream habitats making them unsuitable to the species inhabiting the area. Following four days of heavy sedimentation in an Alaskan stream, Arctic grayling numbers dropped from 78 to 2. Subsequent sediment accumulation on stream margins approached 7.5 to 10 cm (3 to 4 in). It was concluded that the increased sedimentation and habitat changes altered Arctic grayling feeding patterns and caused the entire population to move to another area (Woodward-Clyde, 1976).

Floodplain gravel mining can also result in fish entrapment. Following periods of high water, fish can be trapped by declining water levels in pits adjacent to the main channel or behind berms surrounding the mining site (Moulton, pers. comm.). During construction of the trans-Alaska pipeline, fish entrapment was documented at gravel mining sites on Hess Creek and Tolovana River following fall high water periods. Measurements of dissolved oxygen showed that oxygen levels were inadequate to allow overwintering by the trapped fish (Burger and Swenson, 1977).

Vegetation changes occuring during gravel mining can affect distributions of birds and mammals. Joyce (1980) found that declines in moose and ptarmigan populations occurred in areas where large amounts of vegetative cover were removed during gravel mining, or where changes in hydraulic conditions subjected an area to frequent or permanent ponding and flooding or aufeis development. Joyce (1980) also reported that populations of passerine birds and small mammals were reduced at sites where significant quantities of riparian vegetation were removed.

Generally, when habitats are altered, some species are negatively impacted while others benefit. Moulton (1980) found that the effect of gravel removal on fish populations in Arctic Alaskan streams included: (1) reduction in numbers of all fish in the disturbed area, (2) replacement of one species by another, (3) replacement of one age group by another, or (4) in some cases because of habitat enhancement, an increase in the number of fish, or species, or both. Joyce (1980) concluded that waterbird populations increased where mining resulted in permanently ponded areas. Effects on birds, caribou, wolves, fox and other animals with large home ranges are dependent upon whether decreases or increases in cover or food supply occur (Joyce, 1980).

Filling

Filling can cause severe impacts along the coastline, especially in wetlands. Filling changes aquatic habitats into terrestrial habitats thereby destroying waterfowl breeding grounds, fish spawning areas, wetlands, and productive intertidal areas such as clam beds. If other suitable habitats for reproduction are not available nearby, the species will have to relocate. However, many species such as salmon only spawn in specific areas and if these areas are destroyed by filling, that segment of the population will be lost. Wetlands provide large amounts of nutrients to coastal organisms (Clark, 1977). When wetlands are filled, fewer nutrients are added to coastal waters and primary production decreases. This may ultimately reduce the numbers of fish, birds, and mammals within the coastal area. Wetlands prevent freshwater from moving into ocean waters, and salt water from moving inland. Because wetlands are saturated, fresh water is retained underground in natural reservoirs. When a wetland is filled it can no longer act as a barrier and fresh water may be diverted into the ocean. This effectively lowers the water table, and allows salt water intrusion into the water table (NERBC, 1976).

Dredge Disposal

The primary impacts of dredge disposal are increased siltation and burial of benthic organisms. Turbid waters block light penetration reducing the visual feeding range of fish and decreasing primary productivity. Fine sediments affect juvenile fish by causing inflammation of gill membranes and eventual death (Lynch et al., 1977). Organisms buried by the disposal of dredged material, are killed if they are unable to reach the sediment surface and the overlying water upon which they depend for respiration and food (Morton, 1977; Allen and Hardy, 1980).

Impacts of burial vary with species, depth of burial, and type of sediments deposited. Sessile or attached organisms such as oysters, mussels, and barnacles which cannot burrow up through the sediments are killed by burial. When sediments are anoxic, smaller animals are even more vulnerable to burial because they are unable to reach the surface before they suffocate (Morton, 1977). Small crustaceans respond to oxygen depletion by increased ventilation. This rapidly uses up the remaining available dissolved oxygen (Saila et al., 1972, in Morton 1977). The ability of mussels to emerge from burial appears related to species and size. Emergence of fat mucket (Lampsillis radiata luteola) and pocket book (L. ventricosa) mussels was prevented by 18 cm (7 in) of sand or silt but emergence of pig-toe mussels (Fusconaia flava) was prevented by only 10 cm (4 in) of silt. Mussels emerged from the sediment within a few hours or did not emerge at all (Marking and Bills, in press). Vertical migration investigations with clams, crabs, and benthic worms showed recovery after burial by as much as a meter of like material (i.e. sand on sand, mud on mud), or smothering by as little as a few centimeters covering of unlike material (i.e. sand on mud or mud on sand). Field studies in Virginia and California found benthic recolonization of dredged areas and disposal mounds to be rapid for fine-grained sediment, and to require up to three years for coarse-grained sediments. Recovery in a mudflow (fluid mud) area from pipeline disposal was somewhat more rapid (Saucier et al., 1978). Fluid mud, generated by hydraulic pipeline dredges can flow along the bottom, driven by tidal currents and gravity. Benthic organisms are destroyed when the fluid mud separates them from the overlying water upon which they depend for respiration and food (Allen and Hardy, 1980).

Gravel Pad and Road Construction

Sand and gravel pads are used for year-round roads, camps, air strips, drill sites, storage areas, pump stations, communication sites, and other work sites. Pads provide a firm working surface and protect underlying permafrost from degradation. Pads affect vegetation, alter drainage patterns and can block or alter movements of fish and wildlife (USGS, 1979).

The primary impact of the construction of pads is the total loss of the area covered (vegetation, wetlands, stream bottom, etc.) and that portion of fish and wildlife habitat it contributes. Pads can affect vegetation directly (burial), or indirectly by the dust clouds raised by passing vehicles (USGS, 1979). Dusting of vegetation leads to accelerated spring snow melt and changes in vegetative patterns (Gilliam, 1978).

Gravel pads and road beds can also alter drainage patterns. Ponding can occur on upstream sides of a pad and gullies commonly form on slopes where culverts in pads channelize flow. On permafrost soils, impoundment of water or ponding degrades the underlying permafrost, and channelization of flow through culverts can start thermal erosion problems (USGS, 1979). Changes in vegetation and water levels can have direct and significant effects on nesting and feeding waterfowl and shorebirds.

Fish streams can be impacted by the construction of gravel pads and roadbeds. Runoff from unvegetated pads and roadbeds can increase siltation, and where roads cross streams, fish migrations can be blocked or impeded by improper culverting (USGS, 1979). During construction of the trans-Alaska pipeline with its associated work pads and haul road, blockage of fish migrations occurred where currents in culverts were too strong to allow fish passage, where culverts remained frozen after spring breakup, and where low water crossings did not allow adequate depth for fish passage during low flow periods (Morehouse et al., 1978). If fish cannot reach spawning grounds, or are delayed too long, spawning success is lowered. Inadequately sized, poorly placed, or improperly designed culverts can deny fish access to all upstream areas, and significantly reduce fish populations in the stream system.

Gravel Islands

The oil and gas industry requires stable platforms from which to conduct drilling operations. While conventional jackup or semisubmersible drilling rigs are seasonally feasible in Norton Sound and can be used during exploration, gravel and other artifical islands may be the most economically feasible alternative for year round development drilling and production in shallow waters to 18 meters (60 feet) deep (Hanley et al. 1980; Arctic Offshore, April, 1979). Artificial islands are used during exploratory drilling in the Beaufort Sea. To date, seventeen artificial islands have been constructed in the Canadian Beaufort Sea and along the Alaskan Beaufort Sea coast (Hanley et al., 1980).

Artificial island designs vary. Side slopes, designed to protect the island from waves in the summer and ice in the winter, can be protected by concrete blocks, quarry stone, sand bags, gabions (wire mesh enclosures) filled with sand bags or can be designed with sacrificial beaches. A caisson retained island has been designed for drilling in the Canadian Beaufort Sea. A caisson ring is placed on the sea bed or an underwater berm and fill is only required for the area inside the ring (Hanley et al., 1980).

Depth of water and design of the island determine how much area is taken up by the island and how much fill is required to construct it. Issungnak, an artificial island built off the Mackenzie River Delta in 19.2 meters (63 feet) of water, had a working surface 91 meters (300 feet) in diameter, but enlarged into a circular shape on the sea bottom more than 732 meters (2,400 feet) across (Arctic Offshore, December, 1980). Caisson islands require significantly less fill than conventional gravel islands (see Table 26).

The most obvious impact of gravel islands is the alteration of a portion of nearshore marine habitat into terrestrial habitat. Benthic organisms residing at the site would be buried and important habitats such as spawning and rearing areas will be lost if islands are constructed in these areas. Construction of two artificial islands in waters only 3 to 3.5 meters (10 to 11 feet) deep in Stefansson Sound, Alaska, (Sag Delta

TABLE 26

ARTIFICIAL ISLAND SPECIFICATIONS AND FILL REQUIREMENTS 1/

A. SPECIFICATIONS OF SOME EXPLORATION ISLANDS CONSTRUCTED IN SOUTHERN CANADIAN BEAUFORT SEA[1]

Island Name	Year	Water Depth		Fill Volume		Freeboard		Type
		meters	feet	cu. meters	cu. yards	meters	feet	
Adgo	1973	21	7	38,230	50,000	1	3	Sandbag Retained
Immerk	1973	3	10	183,504	240,000	4.6	15	Sacrificial Beach
Netserk	1974	4.6	15	305,840	400,000	4.6	15	Sandbag Retained
Netserk N	1975	7	23	290,548	380,000	4.6	15	Sandbag Retained
Arnak	1976	8.5	28	1,146,900	1,500,000	5.2	17	Sacrificial Beach
Kannerk	1976	8.5	28	1,146,900	1,500,000	5.2	17	Sacrificial Beach
Kugmallit	1976	5.2	17	237,000	310,000	4.6	15	Sandbag Retained
Isserk	1977	13	43	1,911,500	2,500,000	4.6	15	Sacrificial Beach

B. COMPARISON OF FILL REQUIREMENTS FOR DIFFERENT EXPLORATION ISLAND DESIGNS[1]

Water Depth		Sacrificial Beach Island		Retained Fill Island (Sandbags)		Caisson Retained Island 30 Ft. Set-Down Depth	
meters	feet	cu. meters	cu. yards	cu. meters	cu. yards	cu. meters	cu. yards
6	20	611,680	800,000	191,150	250,000	114,690	150,000
9	30	1,299,822	1,700,000	382,300	500,000	114,690	150,000
12	40	1,911,500	2,500,000	688,140	900,000	229,380	300,000
18	60	3,823,000	5,000,000	1,911,500	2,500,000	688,140	900,000

C. ESTIMATED REQUIREMENTS FOR PRODUCTION ISLANDS[2]

Water Depth		Dimensions	Fill Volume	
meters	feet		cu. meters	cu. yards
7.6	25	213 meters (700 feet) diameter working surface, 7.6 meters (25 feet) freeboard; 4:1 side slopes	665,202	870,000
15	50	213 meters (700 feet) diameter working surface, 7.6 meters (25 feet) freeboard; 4:1 side slopes	1,376,280	1,800,000

Sources: [1] deJong and Bruce, 1978a and b.
[2] Dames & Moore estimates from various sources.

1/ Hanley et al., 1980

No. 7 and Sag Delta No. 8) was expected to result in the physical loss of 1.8 hectares (4.5 acres) and 1.6 hectares (3.9 acres) respectively (Evans et al., 1980).

Other impacts that could result from artificial islands include: 1) changes in circulation patterns and wave refraction; 2) increased turbidity during construction; and 3) siltation of downstream areas. Changes in circulation can affect longshore sediment transport and coastal erosion and deposition rates. Increased turbidity can reduce light penetration thus decreasing photosynthesis and primary productivity; clog feeding mechanisms of filter feeders such as molluscs and polychaete worms; alter fish distributions; and, affect nearshore juvenile fish rearing areas (Evans et al., 1980). Continual erosion of unprotected gravel islands by marine currents and storms, and deposition of eroded material in downstream areas can also impact benthic habitat. Deposition of eroded material in downstream areas can be quite significant during severe storms or over a period of a year's time. In addition, unprotected gravel structures will require continual maintainence and large quantities of gravel to annually replace eroded material.

Table 27 Effects of dredging and filling, gravel mining and gravel islands on fish, wildlife, aquatic plants and their habitats

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
MAMMALS AND BIRDS				
Terrestrial Species	Joyce, 1980	field observation	gravel mining	At sites where significant quantities of riparian vegetation were removed during gravel mining: (1) passerine and small mammal populations were reduced, (2) populations of waterbirds increased where mining resulted in permanently ponded areas, (3) populations of ground squirrels increased where overburden piles were adjacent to or within the site, (4) moose and ptarmigan winter distribution and movements may have been altered and, (5) effects on bears, caribou, wolves, fox and other animals with large home ranges, are dependent upon whether decreases or increases in cover or food supply occurred.
Moose (*Alces alces*) Ptarmigan (*Lagopus* sp.)	Joyce, 1980	field observation	gravel mining	Following gravel removal, decreases in population levels of moose and ptarmigan occurred in areas where large amounts of vegetative cover were removed or where changes in hydraulic conditions occurred that subjected the area to frequent or permanent ponding and flooding or aufeis development. The annual occurrence of these types of hydraulic stress impeded rapid vegatative recovery.
Small Mammals Ground Squirrels	Joyce, 1980	field observation	gravel mining	At gravel mining sites studied, presence of overburden sites in a disturbed area or in an area subjected to flooding, permanent ponding or aufeis development was correlated with increased populations of ground squirrels and other small mammals. Overburden piles composed of a mixture of silts, organics, woody slash, root stocks, and debris, located at least 1 to 1.5 m (3-5 ft) above normal water levels, and placed in the middle of large scraped areas rather than along the edge were judged to be of the most benefit.
Waterbirds	Joyce, 1980	field observation	gravel mining	Pit mining and gravel extraction from sites separated from the active floodplain increased waterbird habitat. The quality of the new habitat was related to its size, shoreline diversity and configuration, water depth diversity, shoreline cover, presence of islands, and food availability.
FISH				
Salmon (*Oncorhyrchus* sp.)	Dutta, 1976	unknown	dredging in river	As many as 26,000 salmon fry/day were entrained by a hydraulic dredge. Fry migration was reported to be 20 million/day during period the dredge was operating.
Chum Salmon (*Oncorhynchus keta*)	Sheridan, 1967	unknown	gravel mining	Four years after gravel mining on a salmon stream in southeastern Alaska, the pits had filled with gravel and, 500 to 1000 chum salmon spawned in a channel running through the fill material.
Salmon (*Oncorhyrchus* sp.)	Darnell et al., 1976	unknown	turbidity	In clearwater streams, turbidity may act as barrier to migrating salmon.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Arctic grayling (Thymallus arcticus)	Woodward-Clyde, 1976	literature review	sedimentation	Following four days of heavy sedimentation in an Alaskan stream, Arctic grayling numbers in the portion of the stream sampled declined from 78 to 2. Sediment accumulation on stream margins approached 7.5 to 10 cm (3 to 4 in). It was concluded that the increased sedimentation and habitat changes altered Arctic grayling feeding patterns and caused the entire population to move to another area.
Steelhead (Salmo gairdneri)	Orcutt et al., 1968	unknown	gravel mining	Steelhead were observed spawning in Idaho streams in areas where bulldozers had removed gravel. Removal and loosening of the gravel evidently improved intergravel flow of water thus contributing to its value for spawning.
Trout	Spaulding and Ogden, 1968	unknown	gravel mining	Sand and gravel mining in trout streams resulted in compaction of the substrate and subsequent loss of spawning habitat.
Trout	Saunders and Smith, 1965	field observation	siltation	The effects of increased siltation on populations of trout in Ellerslie Brook on Prince Edward Island, Canada, were studied. Results showed that the standing stock of trout was reduced because hiding places and spawning areas were silted over.
Fish	U.S. Army Corps of Engineers, Portland Dist., 1973	unknown	dredging and dredge disposal	A decline in fish catch and species variety was noted at both dredging and disposal sites on the Columbia River 40 days after dredging. However, at sites that were only slightly disturbed by dredging, there was an increase in catch.
Fish	Webb and Casey, 1961	unknown	gravel mining	Physical changes in a fish stream in Idaho following gravel removal included a reduction in habitat due to straightening of stream meanders, elimination of pools, silt accumulation in pools, and a decrease in suitability of riffles for spawning. During the actual dredging operation, fish populations were reduced by 99% in the dredged area. One year after the study, population numbers had risen but remained lower in the dredged area than in surrounding areas.
Fish	Northern Engineering Services Company Ltd. and Aquatic Environments Ltd., 1975	unknown	gravel mining	Fish entering borrow pits in the Sagavanirktok River through breaches in the berms were trapped when channels containing the fish were bermed by lowering water levels. Fish inhibiting settling basins were killed when these ponds froze solid during the winter.
Fish	Lynch et al., 1977	literature review	siltation	The deposition of sediments in fish spawning streams reduces the flow of water through the interstitial spaces in the gravel, suffocating eggs, embryos, and alevins. Fine sediments affect juvenile fish by causing inflammation of the gill membranes and eventual death. Fry and fingerling trout reared in turbid water are more prone to bacterial infection of their gills due to gill abrasion by the sediments in the water.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
INVERTEBRATES				
Dungeness Crab (Cancer magister)	Allen and Hardy, 1980	literature review	hydraulic dredging	Entrainment of slow moving nekton during hydraulic dredging was cited as the cause of large scale dungeness crab mortality in Gray's Harbor, Washington. It was not stated whether the nekton were crab larvae or food items.
Oysters Mussels Barnacles	Morton, 1977	literature review	disposal of dredged material	Sessile or attached organisms such as oysters, mussels, and barnacles which cannot burrow up through the sediments are killed by burial. When sediments are anoxic, smaller animals are even more vulnerable to burial because they are unable to reach the surface before they suffocate.
Freshwater Mussels	U.S. Army Corps of Engineers, St. Paul Dist., 1974	unknown	disposal of dredged material	Ten years may be required for substrate to be recolonized by mussels following dredge disposal.
Freshwater Mussels	Marking and Bills, (in press)	unknown	disposal of dredged material	Ability of mussels to emerge from burial appeared related to species and size. Emergence of fat mucket (Lampsilis radiata luteola) and pocket book (L. ventricosa) mussels was prevented by 18 cm (7 in) of sand or silt but emergence of pig-toe mussels (Fusconaia flava) was prevented by only 10 cm (4 in) of silt. Mussels emerged from coverage within a few hours or did not emerge at all.
Bivalve Molluscs	Cardwell et al., 1976	unknown	siltation	Larval stages of bivalve molluscs, such as Pacific oysters, quahog clams, American oysters, and European oysters, are sensitive to natural sediments in the water column. Sedimentation interferes with shell formation, growth and survival. Larvae of these species will not settle out or develop in areas with silty waters.
Polychaete worms (Capitella capitella) (Polydora ligni) (Streblospio benedicti) (Pseudopolydora kempi)	McCauley et al., 1976	field observation	maintenance dredging	Four species of polychaete worms were observed for eight weeks after maintenance dredging. Capitella capitata seemed to thrive best in recently deposited sediments but did not do well where sediments were overturned several times weekly. Polydora ligni thrived where sediments were overturned frequently and where sawdust and wood debris abounded. Streblospio benedicti and Pseudopolydora kempi thrived under conditions where either frequent overturning or recent sedimentation occurred and may be dependent upon suspended organic matter in the epibenthic water. Both species can apparently leave their sediment tubes when disturbed, swim rapidly, and rebuild tubes quickly.
Small Crustaceans	Saila et al., 1972, in Morton, 1977	unknown	disposal of dredged material	Small crustaceans respond to oxygen depletion (which can be caused by disposal of dredged material with high biological oxygen demand) by increased ventilation. This rapidly uses up the remaining available dissolved oxygen.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Benthic Organisms	Allen and Hardy, 1980	literature review	dredging	During initial channel construction, and at each maintenance dredging, 75% or more of the benthic organisms are removed from the site. Although recolonization of dredged benthic habitat may reach original biomass within two weeks to four months, original species diversity is seldom achieved. Recolonization is generally by opportunistic species which may be less valuable in the food chain.
Benthic Organisms	Taylor and Saloman, 1967	unknown	dredging	Recolonization of newly dredged channels in Florida was negligible after ten years and none of the 49 species of fish caught in the channels (as compared to 80 species caught in undredged areas) were demersal. A decrease in numbers of invertebrates in the channels was attributed to the soft silt-clay dredged sediments replacing the sand-shell undredged sediments. Decreased oxygen supply in and above the dredged channel substrate was also considered a prime factor.
Benthic Organisms	Bingham, 1978	literature review	disposal of dredged material	Results of a study at a (deep water) disposal site for contaminated dredged material in Puget Sound showed: (1) The greatest detrimental impact on benthos resulted from burial in excess of 0.5 m (1.6 ft); (2) benthic repopulation was by horizontal migration; (3) population density had not recovered in the center of the disposal area nine months after disposal; (4) because of invasion of opportunistic species, species diversity was greater in the center of the disposal area nine months after disposal; (5) at nine months both species density and diversity were greater at the margins of the disposal area than reference areas; and (6) effects of the disposal operation were confined to the immediate disposal site areas.
Benthic Organisms	Saucier et al., 1978	summary of field studies	disposal of dredged material	At an onshelf disposal site off the Columbia River, no water column effects were noted from discharge of 600,000 cubic yards of dredged material. Physical mounding of the material was evident at the site. Recolonization of the coarse-grained material by organisms native to the area was slow (1 to 3 years to biological stability).
Benthic Organisms	Saucier et al., 1978	unknown	disposal of dredged material	Vertical migration investigations of selected organisms (clams, crabs, and benthic worms) showed them to recover after burial by as much as a meter of like material (i.e., sand on sand, mud on mud) or to have been smothered by as little as a few centimeters covering of unlike material (i.e., sand on mud or mud on sand). Field studies in Virginia and California showed benthic recolonization of dredged areas and disposal mounds to be rapid for fine-grained sediment and to require up to three years for coarse-grained sediments. Recovery in a mudflow (fluid mud) area from pipeline disposal was somewhat more rapid.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Benthic Organisms	Allen and Hardy, 1980	literature review	pipeline dredges, disposal of dredged material	Fluid mud was reported as commonly generated by pipeline dredges. Fluid mud can be driven by tidal currents and gravity and flow along the bottom. Benthic organisms are destroyed when the fluid mud separates them from the overlying water upon which they depend for oxygen and food.
Benthic Organisms	Clark and Terrell, 1978	literature review	turbidity during disposal of dredged material	Benthic organisms 60 or more meters (200 ft) from pipeline construction sites have been impacted by turbidity when high pressure jets are used.
Benthic Organisms	Webb and Casey, 1961	field observation	placer mining (dredging)	Placer mining in an Idaho trout stream reduced benthic organisms 99% in the immediate area. Organisms were affected up to 0.5 km (0.3 mi) downstream. Benthic populations recovered within one year. Fish populations were eliminated at the dredge site and reduced 0.5 km (0.3 mi) downstream. Some recovery occurred at the downstream site. Changes in species composition were noted.
Benthic Organisms	Oregon State Game Commission, 1955	unknown	gold dredge mining (removal and washing of gravel)	Gold-dredge siltation in the Powder River in Oregon, affected fish food organisms as far as 64 km (40 mi) downstream.
PLANTS				
Spartina alterniflora	Gambrell et al., 1978	literature review	disposal of dredged material	*Spartina* growing on mercury contaminated dredge material may transfer sediment bound mercury to the water column. Total uptake by *Spartina* in a Georgia marsh was 0.7 $mg/m^2/yr$. Much of this was released to surrounding waters through the leaves.
Vegetation	USGS, 1979	literature review	gravel pads	Gravel pads can affect vegetation directly (onsite) by burial or indirectly by the dust clouds raised by passing vehicles.
Phytoplankton	Clark, 1977	literature review	turbidity	The resuspension of bottom sediments causes the water to become turbid, limiting the amount of light entering the water column. When light penetration is reduced, the growth rates of phytoplankton are also reduced, limiting the amount of food available for other members of the food web including zooplankton, fish, birds, and marine mammals.
HABITATS				
Wetlands	Quigley, 1977	field observation and aerial photo interpretation	filling	A sand and gravel berm approximately 10 m wide and 50 cm high built through 0.5 km of a Wisconsin wetland to support a utility transmission line, resulted in vegetative changes in the wetland. The berm also affected water flow patterns in the wetland. The resulting differences in water level on either side of the berm were accentuated in dry years, with differences at times becoming greater than 1.5 m.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Shallow waters and wetlands	Allen and Hardy, 1980	literature review	disposal of dredged material, fill, island construction	Use of dredged material to create islands or to fill wetlands as sites for industry or recreation causes a) the permanent loss of wetlands or water bottoms; b) changes in water circulation patterns and flushing rates; and c) secondary impacts from industrialization of the site such as increased surface runoff, and point and nonpoint source pollution.
Freshwater	Wechsler and Cogley, 1977	unknown	disposal of dredged material	Turbidity is more persistent in soft freshwater than in hard water (200 mg/l or greater dissolved solids) or saltwater where induced floculation and consequently more rapid settling occurs.
Rivers	Allen and Hardy, 1980	literature review	dredging	Altering river channels through new channel construction or deepening projects can cause changes in hydrology and stream gradients impacting the river, marshes, backwaters, and the entire floodplain. Channelization of small streams eliminates wetlands and backwaters, destroys fish cover, causes water temperature to rise and increases the sediment load and turbidity.
Rivers	Moulton, 1980	field observation	gravel mining	Habitat alterations occurring following gravel removal in streams included: 1) a shift from a moderately compacted gravel substrate to a very loose, unconsolidated sand-gravel substrate, usually with considerable intergravel flow, 2) a shift from a smooth, paved substrate which produced near laminar flow to a more porous, irregular substrate providing turbulent flow, 3) loss of bank cover, 4) loss of deep pools, instream cover, and slack water areas behind obstructions, 5) increased braiding, 6) increased backwater channels with increased siltation in these areas, 7) changes in dissolved oxygen and water temperature and, 8) increased aufeis formation. In some areas increased habitat diversity occured.
Rivers	Rundquist, 1980	field observation	gravel mining	In arctic rivers where stream width and depth have been increased by gravel removal (such as by in-channel mining), declines in stream flow velocity could cause ice floes to gather. At the downsteam end of the gravel removal area these floes could jam where the channels constrict back to the natural width. This ice jam could cause flooding in and upstream from the gravel removal area and possible bed scour beneath the ice jam. River channels which are widened causing shallower depths, such as by removing bars adjacent to the channel, could cause ice jamming by grounding the ice floes. Obstructions, such as dikes, left in the stream channel could also contribute to ice jamming.
Rivers Fish streams	Rundquist, 1980	field observation	gravel mining	Ratios between surface flow and subsurface flow were altered at several sites following gravel removal. At one site, stream flow entered the gravel removal site and spread out through loose, uncompacted gravel resulting in a substantial reduction in surface flow during low water periods. Intergravel flow was still evident 13 years after the site was worked. At

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
				another site surface flow ceased entirely for a period of two years. Greatest impact on surface flow was at sites where gravel removal occurred on the downstream side of a sharp meandering bend allowing surface flow to leave the channel and spread out. Where sediments (either exposed by gravel removal or deposits resulting from sediment load dumping) were loose and uncompacted, substantial intergravel flow resulted. Where insufficient flow is present, fish migrations would be blocked, and spawning grounds lost.
River	Forshage and Carter, 1973	field observation	gravel mining	Sites on the Brayos River in Texas were monitered before, during and six months after gravel removal. Gravel removal increased the depth of the river and the substrate changed from gravel to sand. Significant changes in the substrate were apparent for 1.6 km (1 mi) below the site with turbidity detectable for 12 km (7.5 mi) downstream. Benthic populations were reduced 97% at the site, and 50% 2.7 km (1.7 mi) downstream. Benthic organisms were affected 6 km (3.8 mi) below the dredging site. Following gravel removal, species composition of the fish population changed. There was a substantial decrease in spotted bass with a pronounced increase in river carp, sucker and white crappie.
Nearshore waters and beach	Allen and Hardy, 1980	literature review	beach nourishment	The greatest adverse impacts associated with beach nourishment appeared to be turbidity at the time of disposal and for several months thereafter as the fine-grained material is worked from the sand and transported down current. Smothering of benthic organisms appeared to be a minor short-term impact.
Littoral zone	Allen and Hardy, 1980	literature review	dredging and dredged disposal	At times, it is preferable to dispose of sand dredged from nearshore and river channels in the littoral zone rather than release it in deep water where it becomes unavailable to littoral transport processes. Deep water disposal leads to a deficit sand budget in the littoral zone, which will affect littoral zone organisms and cause beach erosion.
Estuary	Allen and Hardy, 1980	literature review	disposal of dredged material	The severity of impact on the water column from dredge disposal in estuarine habitats is strongly related to the degree of dilution and mixing that occurs.
Estuary	Breuer, 1962	unknown	disposal of dredged material	Placement of fill in one end of South Bay in Texas altered circulation patterns; Boca Chica Pass filled in; circulation in the bay was reduced; depth decreased from 1.2 to 0.4 m (3.9 to 1.3 ft), and; the oyster population was destroyed. There was also a decrease in fish and invertebrate populations.
Estuary	Allen and Hardy, 1980	literature review	disposal of dredged material	Long term anoxia (oxygen depletion) can occur when highly organic sediments are discharged. Impacts are most likely to occur in poorly mixed waters receiving highly organic dredged materials.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Estuary River	Barnard, 1978	literature review	turbidity	Silt curtains can be used around a disposal site to reduce water column turbidity as much as 80% to 90% in areas where currents are less than 5 cm/sec. Use of curtains was not recommended where current velocities exceed 50 cm/sec (1 knot) as curtains are most effective in calm water.
Bays	Allen and Hardy, 1980	literature review	dredging	Changes in the bottom topography due to construction of the Mobile (Alabama) ship channel have contributed to the problem of annual oxygen depletion in Mobile Bay. Water in depressions in the bay bottom becomes depleted of oxygen. The oxygen depleted water is occasionally moved shoreward by wind and wave action resulting in stress to the biota.
Shallow bay	Kaplan et al., 1974	unknown	dredging	Productivity was drastically reduced in a small shallow bay in Long Island, New York, following dredging of a navigational channel. Changes in current velocity, modifications of substrate type and land use changes brought on by the new channel were cited as causes.
Coastal waters	Allen and Hardy, 1980	literature review	dredging	Effects on coastal waters from dredging include increased turbidity, increased oxygen demand and releases of contaminants and nutrients. Turbidity at the dredge site is usually not as great as turbidity at the disposal site. Effects vary widely with different equipment types and operator efficiency.
Coastal waters	Allen and Hardy, 1980	literature review	dredging	The net result of new channel construction may be a general increase in turbidity as the channel acts as a trap for sediments and contaminants which are then resuspended by boat traffic, wave action, or currents. Maintenance dredging, although temporarily increasing turbidity may decrease long term turbidity by deepening the channel, thereby decreasing resuspension of sediments by boat traffic.
Coastal waters	Allen and Hardy, 1980	literature review	dredging	New channel construction may cause changes in circulation patterns, salinity, sediment input and deposition, sediment supply to the coast, and nearshore wave refraction and defraction patterns.
Marine waters	Allen and Hardy, 1980	literature review	disposal of dredged material	Factors affecting dispersal of dredge material include grain size and other characteristics of the material, currents, tides, storms, bottom topography, vessel traffic, and depth.
Marine waters	Barnard, 1978	laboratory studies	disposal of dredged material	1% to 3% of dredge material discharged remains suspended in the water column. The remaining slurry decends rapidly to the bottom where it may remain as a mound or, on slopes greater than 0.75 deg (1:76), may become fluid mud and move downslope for as long as the slope is maintained.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
				Laboratory studies determined that water column turbidity could be controlled to a great extent by using different discharge configurations. A simple open-ended pipeline, discharging above and parallel to the surface, maximized the dispersion of the slurry throughout the water column and produced a thin, but widespread fluid mud layer. In water depths in excess of 2 m (6.5 ft) the dispersion of the material in the water column was decreased by vertically discharging the slurry through a 90-degree elbow at a depth of 0.5 to 1 m (1.5 to 3 ft) below the water surface. Most water column turbidity was eliminated by using such a diffuser system at the end of the pipeline. The mounding tendency of the fluid mud was maximized by this configuration thereby minimizing areal coverage.
PHYSICAL PROCESSES				
Drainage	USGS, 1979	literature review	gravel pads	Gravel pads for roads and structures commonly alter drainage to form ponds which affect ice-rich permafrost uphill from the pad. Gullies commonly form on slopes where culverts in pads channelize flow.
Permafrost and drainage patterns	USGS, 1979	literature review	gravel pads	Permafrost can grow upward or aggrade under thick gravel pads used for roads and airfields. On slopes up to 25 percent, growth of permafrost into the gravel pads causes the water flowing through the active layer "upstream" from the pad to be impounded. The active layer is a surface layer of ground that is alternately frozen each winter and completely thawed each summer. Impoundment or ponding degrades the underlying permafrost. Attempts to relieve the problem by placing culverts through the pad channelize the water downstream from the culvert and start thermal erosion problems.
Permafrost	USGS, 1979	literature review	gravel pads	Layers of styrofoam insulation have been used as a substitute for a part of the gravel required to build a pad, to cut costs and to conserve gravel. Styrofoam as an alternative to gravel as an insulation material has not been adequately time tested.

Sensitivity of Areas and Recommended Mitigative Measures

Areas in the northern Bering Sea and Norton Sound were ranked as having low, moderate, or high sensitivity to the impacts of dredging and filling, gravel mining, and gravel islands (see Map E). These designations were based on available data and were made after evaluating the following criteria:

1. The sensitivity of each fish and wildlife species or habitat to dredging and filling, gravel mining, and gravel islands.

2. Species sensitivity to dredging and filling, gravel mining, and gravel islands during the various stages of their life history.

3. The time of year that these critical life history stages occur and the period during which each species would be most affected by dredging and filling, gravel mining, and construction of gravel islands.

4. The location of habitats where critical life history stages occur.

5. The productivity of the habitat.

6. The uniqueness of the habitat.

7. The species' population numbers and relative importance of the population.

8. The degree to which the impacts of dredging and filling, gravel mining, and gravel islands could be mitigated.

Specific considerations and assumptions that were made during the ranking process included:

1. Habitats such as freshwater streams, eelgrass beds, wetlands, tideflats, estuaries and lagoons are likely to be most affected by the adverse impacts of dredging and filling, gravel mining, and gravel islands. These habitats are generally highly productive areas that are extremely susceptible to changes in circulation or drainage patterns, or to the impacts of siltation.

2. The species most susceptible to the impacts of dredging and filling, gravel mining, and gravel islands would be those dependent upon the habitats described in Map D during critical life history stages. Such species and life history stages include: salmon, whitefish, sheefish and other fish rearing, spawning and feeding in freshwater streams; herring spawning in nearshore waters; and waterfowl nesting and staging in wetlands.

3. The habitat destruction caused by dredging and filling, gravel mining, and gravel islands is more likely to impact a species

if that species is restricted to a relatively small area during a critical life history stage. Species which utilize a discrete habitat during a critical life history stage were ranked as highly sensitive. Such species and habitats include: herring spawning areas, seabird colonies, peregrine falcon nesting/use areas, and walrus and spotted seal haulouts.

4. A moderate sensitivity designation was applied to those areas where it was felt the adverse impacts of dredging and filling, gravel mining, and gravel islands could be mitigated. In these areas, critical life stages of species are not confined to highly sensitive habitats such as wetlands, freshwater streams, tideflats, etc. Areas ranked as moderately sensitive include moose and muskox wintering areas, raptor nesting areas, nearshore fish rearing areas and subsistence, commercial, and sport fishing areas.

5. Fucus and kelp beds, although highly productive habitats which would be affected by the adverse impacts of dredging and filling, gravel mining, and gravel islands, were not ranked as highly sensitive due to their abundance in eastern Norton Sound. Herring spawning areas (Fucus is the primary spawning substrate) were ranked as high sensitivity and those Fucus beds within spawning areas are included in the high sensitivity ranking.

Sensitivity Designations and Mitigative Measures

LOW SENSITIVITY AREAS

The designation of low sensitivity applies to areas where impacts of dredging and filling, gravel mining, and gravel islands on fish and wildlife would be less adverse than in moderate or high sensitivity areas. Such areas would include. 1) areas where there were low numbers of sensitive species 2) areas where sensitive species are wide spread.

Dredging and filling activities gravel mining and building of gravel islands within low sensitivity areas should be conducted according to existing environmental regulations such as U.S. Army Corp of Engineers permits 404 and 10; Department of Environmental Conservation's 401 certification; Department of Natural Resources, Division of Land and Water Management Tideland Permit; local zoning ordinances; and Coastal Zone Management guidelines.

MODERATE SENSITIVITY AREAS

The designation of moderate sensitivity applies to areas where adverse impacts from dredging and filling, gravel mining and gravel islands could be prevented, minimized or ameliorated. Habitats included in this category are:

1. *Fucus* and kelp beds
2. King crab concentration areas

3. Salmon nearshore migration areas and nearshore fry and juvenile rearing and feeding areas

4. Arctic char and sand lance concentration areas

5. Herring wintering areas, nearshore feeding and rearing areas and possible spawning areas

6. Capelin spawning and possible spawning areas

7. Juvenile fish nearshore rearing areas

8. Seabird concentration areas on water at base of colonies

9. Waterfowl molting areas

10. Raptor nesting areas

11. Possible polar bear denning sites

12. Moose winter concentration areas, and muskox winter and calving concentration areas

13. Grizzly bear spring feeding areas and denning areas

14. Commercial, subsistence and sport fishing areas; subsistence king crab harvest areas; commercial and subsistence herring harvest areas; and subsistence clam harvest areas

In areas of moderate sensitivity, dredging and filling, gravel mining, and the building and siting of gravel islands should be undertaken according to existing environmental regulations the following guidelines:

Dredging and Gravel Mining - General

1. Dredging and gravel mining should be avoided in highly sensitive fish and wildlife habitats (see Map E).

2. Before major dredging projects are planned, site specific studies should be conducted in the area under consideration to determine local oceanographic and hydrological conditions including: circulation

patterns, temperature, salinity, and dissolved oxygen. The biological productivity of the area should also be evaluated and the location of vital habitats identified. This information should be used to plan and schedule dredging so that minimal environmental damage occurs.

3. Detailed plans for dredging and gravel mining operations should be submitted to resource management agencies well in advance of proposed activities so that operational delays can be eliminated and site specific mitigating measures may be developed to protect local fish and wildlife resources from unnecessary impacts.

4. Activities which are likely to require dredging, such as the construction of nearshore facilities and onshore pipeline routes, should be sited where minimal dredging would be required.

5. Dredging and mining activities should be scheduled to avoid breeding periods and other critical life history stages of sensitive species (see Table 28).

6. Dredging should be conducted in a manner which will prevent the release and spread of silty bottom sediments with a high biological oxygen demand into the water column. "Silt curtains" or "diapers" may be used to retain sediment laden waters near the dredge site. However, silt curtains are only effective in still waters.

7. Hydraulic dredges should not be used in areas which support large populations of larvae or juveniles of commercially or environmentally important marine species which can be entrained or injured in the pumps and dredge lines. In areas with large populations of larval or juvenile marine organisms, a clam shell dredge produces fewer impacts.

8. Silt levels from dredging operations should be at ambient levels by the time they reach sensitive habitats.

9. Operating controls for dredges should be established which will reduce adverse environmental impacts.

10. Because of the scarcity of gravel in Norton Sound, quarry rock and alternate materials should be used for construction whenever possible.

11. Where possible, gravel from abandoned structures such as tailing piles, drill pads or airstrips, should be reused to avoid impacts to watercourses and aquatic habitat.

12. Upland and offshore gravel sites are preferred over floodplains and nearshore areas. Impacts resulting from transportation of gravel and other secondary impacts associated with mining operations need to be considered when selecting a site. The site selected should be that which would result in the least total impact.

13. Gravel mining sites should not be located within the annual floodplains of fish streams or rivers, unless feasible alternatives are non-existent. Gravel mining in floodplains can result in channel changes, channel blockages, siltation, and fish entrapment.

14. Gravel mining should not occur on spits protecting lagoons, in the lagoons themselves, or in nearshore areas.

15. Gravel mining in wetlands should be avoided.

16. Development of a minimal number of upland, intensive-use gravel sites is preferable to a proliferation of small sites; minimization of sites reduces access road requirements and limits the area of habitat disturbance.

17. A mining site should meet the long term requirements for all activities in a given area; sites slated for one-time use by a single project should be avoided.

18. Deeply mined gravel pits should be converted to water reservoirs where the need exists. This will provide a dependable winter supply of water, and will preclude the need for water removals from biologically sensitive habitats such as fish overwintering areas.

<u>Dredging for Channels</u>

1. Appropriate choices should be made for the location and design of channels. Plans should include: 1) proper alignment of the

channel to minimize erosion and maintenance dredging; 2) minimum dimensions for length, width, and depth of channel to limit destruction of productive marine habitat and maintain natural circulation patterns; 3) appropriate choice of dredge type which will minimize siltation (usually suction dredge); 4) establishment of beneficial operating controls for dredging operations which will minimize short term impacts on fish and wildlife; 5) proper disposal of spoil in upland sites; and 6) time of year in which dredging operations would encounter the least amount of biological activity (see Table 28).

2. Existing natural channels should be utilized to the greatest extent possible. New channels should be located so as to prevent the loss of vital areas and to avoid erosion of shorelines.

3. Channel dredging can be avoided in most vital habitats by limiting dredging to natural channels. Depositional areas will require continual maintenance dredging. All vital habitats should be identified during the planning phase of each dredging operation and a buffer zone of several hundred feet or more should be maintained between those areas and dredging operations. Buffer zone boundaries should be determined on a case-by-case basis.

4. Minimize the length, depth, and width of the channel to maintain the natural pattern of water circulation, to avoid major salinity alterations, and to protect vital habitats. Excessively

wide channels may lead to an unnecessary loss of vital habitat areas such as clam beds or eelgrass beds. In general, a navigation channel needs to be no wider than about three or four times the width of the largest vessel for which it is designed. Similarly, channels do not need to be deeper than about 4 feet beneath the deepest draft vessel at low water, provided that traffic moves at moderate speeds to reduce stirring up the bottom where fine sediment has accumulated. In many cases it is not unusual to add to this 4 foot depth an additional foot or so to accommodate siltation or slumping. This will further reduce the frequency of maintenance dredging.

5. To avoid excessive slumping of the adjacent bottom into the channel and repeated maintenance dredging, channel sides should be dredged out to a final stable slope, or "angle of repose" during the initial operation. The exact cut will depend on local geohydrological conditions.

6. Projects which would cause accelerated shore erosion should be avoided, or operated in such a manner as to eliminate erosion-inducing effects. Dredging too close to the shore in shallow-water areas may cause severe shoreline recession, both from channel slumping and from direct erosion of banks, and should be avoided.

7. Dredging near the toe or face of a bluff should be avoided as it exposes the bluff to increased erosion.

8. New channels should not be created between freshwater aquatic systems and coastal waters.

9. Avoid alteration of natural water channels through straightening, deepening, or diking.

Dredging for Pipeline Laying

1. Pipeline routes should avoid highly productive, economically valuable, or unique habitats.

2. If important habitats cannot be avoided when planning pipeline routes, avoid dredging during such sensitive periods as fish migration and spawning, and waterfowl nesting and staging. For additional information on species and timing see Table 28. Onshore pipeline laying should be conducted during the winter when the ground is frozen and impacts caused by construction equipment are minimized.

3. Limit dredging to the smallest area necessary for pipeline placement.

4. Avoid permanently blocking surface drainages during pipeline installation. Elevated pipelines and roads should be adequately culverted. Soil over buried pipelines should be contoured to original slopes, and banks at stream crossing should not be altered. Care should be taken to prevent slumping in permafrost soils or altering drainage patterns.

5. Whenever possible, "double ditching", the removal of topsoil and vegetation first and replacement of it last, should be used. This promotes more rapid restoration of vegetation.

6. Limit equipment and activities to the pipeline right-of-way

7. Use hydraulic dredges instead of jet systems when bottom sediments are silty and siltation is likely to affect important habitats. Hydraulic dredges are capable of pumping dredged spoils up to one mile from the site, thus protecting habitats adjacent to the dredged area.

8. Use silt curtains (polyethylene sheets hanging from float lines to the water's bottom) to trap silt and sediment. Silt curtains, however, are effective only in still waters.

Dredging in Streams

1. Dredging should occur only during low water periods in order to minimize siltation.

2. Dredging should not occur in known or suspected fish spawning or nursery areas. Wherever possible dredging should occur below spawning areas.

3. Dredging operations must follow procedures that will minimize the resuspension of instream materials.

4. Dredging should occur during periods of lowest biological activity.

Gravel Mining in Marine Areas

1. Gravel mining should be avoided in highly sensitive fish and wildlife habitats (see Map E).

2. Gravel should not be mined from spits, beaches, deltas of rivers that support fish, lagoons, estuaries, or barrier islands.

3. Gravel mining site selection should be based on a study which considers not only gravel availability but also concentrations of biological resources; commercial, recreational and subsistence harvest activities; and effects of siltation on downstream habitats.

4. Silt control measures should be practiced in areas of biological productivity or where silt could be carried into productive habitats.

5. Organic overburden from offshore mining areas should be backfilled into previously mined areas to speed recolonization of the area by marine life.

Gravel Mining in Upland Areas

1. Detailed mining plans should be submitted to resource management agencies well in advance of mining operation to expedite permitting. Site specific mitigating measures should be developed if necessary to protect local wildlife resources from unnecessary impacts.

2. Where mining occurs in areas which support critical life history stages (esp. grizzly bear denning, raptor nesting, and moose and muskox wintering) operations should be timed to avoid those life history stages (see Table 28).

3. Impacts of roads and other support activities and structures should be considered during site selection.

4. Sites should be located so as to prevent mass wasting into fish streams.

5. Vegetation removal should be limited to the area necessary for one years operation.

6. Mined areas should be revegetated and restored to original contours or used for water storage.

Gravel Mining in an Annual Floodplain

Annual floodplains are the least desirable location for gravel mining. Mining in offshore marine areas or in uplands is preferable. In an area where the only feasible gravel source is within an annual floodplain, the following guidelines should be followed to minimize impacts.

1. Floodplains of streams which do not support fish populations should be considered as gravel sources before those streams that support anadromous or non-anadromous fish. Because of increased risk of hydrological changes in the stream, floodplains of anadromous fish streams should be considered last.

2. Where mining must occur in active floodplains, braided rivers should be considered as primary gravel sources; other river configurations, listed in order or likelihood of causing the least physical change, are split, meandering, sinuous, and straight.

3. When small quantities of gravel are required (approximately 50,000 m^3 or less), select sites that will scrape only unvegetated gravel deposits.

4. When large quantities are required (in excess of 50,000 m^3), select larger rivers containing sufficient gravel in unvegetated areas, or select terrace locations on the inactive side of the floodplain and mine by pit excavation

5. Consider length, location and other impacts of access roads in site selection. Mined areas should be on the same side of a stream as the access road to minimize stream crossings.

6. Work should be scheduled to avoid peak biological events such as local fish migration and spawning, bird and mammal breeding, nesting, and rearing-of-young. Critical habitats such as spawning and overwintering areas should be avoided.

7. Riffle areas should be avoided except in the following situations:

   a. When more rapid site recovery is desirable.

   b. When the riffle is an unproductive aquatic habitat because of cementation or infiltration by fine sediments.

   c. Where deepening the thalweg may reduce or eliminate aufeis development.

   d. In a long riffle, excavation may be acceptable near the middle of the riffle.

8. Vegetated areas should not be disturbed when sufficient quantities of gravel can be obtained in unvegetated areas of floodplains.

9. Material removed from unvegetated and exposed (de-watered) bars of a watercourse should only be removed to the existing ice or water level. Following mining, bars should be sloped to enhance drainage.

10. Where removal must occur in vegetated areas, preference should be given to locations in dominant, homogeneous vegetative communities.

11. If mining in vegetated areas, all overburden and vegetative slash and debris should be saved for use during site rehabilitation to facilitate vegetative recovery. This material should be piled or broadcast in a manner so that it will not be washed downstream.

12. Material sites within the active floodplain should not disturb the edge of active channels or form new high-water channels through the site.

13. Site configurations should avoid use of long straight lines. Sites should be shaped to blend with physical features and surroundings.

14. Gravel mining should occur in such a manner that the water flow of the watercourse is not rechanneled, blocked or diverted.

15. When scraping in active or inactive floodplains, maintain buffers that will contain active channels to their original locations and configurations.

16. Banks of watercourses should not be altered. Undercut and incised vegetated banks especially should not be altered.

17. Stream crossings should be selected at points where no alteration of the banks is necessary.

18 Equipment should not enter or cross an active (open flowing) channel of the watercourse.

19. Movement of equipment through willow (Salix) stands should be avoided whenever possible.

20. Mining should occur in such a manner that berms, potholes, and/or depressions that could cause fish entrapment are not created.

21. Pit mining if required, should be located in areas where there is a low probability of diverting active stream channels into the mined area. Such areas include terraces, inactive floodplains, or stable islands with adequate buffers.

22. Pit excavations should be separated from the active floodplain by a buffer designed to maintain this separation for two or more decades.

23. If pits are left in floodplains, an outlet should be constructed to provide escape for fish trapped during high water. A pit connected to a fish stream, if properly designed, can provide for fish rearing and overwintering. Where a pit is adequately protected from flooding, and will not be used for fish habitat, waterfowl and shorebird habitat can be created by providing a diversity of water depths.

24. Pit outlet channels should be deep enough to allow fish passage during low flow conditions and be as narrow as possible. All outlet channels should be at the downstream end of the pit, angled downstream, and connected to a non-depositional area of the main channel. Outlet channels should be constructed at the end of site rehabilitation to minimize siltation in the river.

25. Where gravel washing operations are required in floodplains, wash water should be recycled with no effluent discharge to the active floodplain. If settling ponds are required, they should be designed to provide adequate retention time for site-specific conditions. Outflows should be constructed to avoid fish entrapment.

26. Upon completion of material removal the mining site should be graded smooth with all berms and potholes removed, and all depressions filled to prevent entrapment of fish. Stored material should not be stockpiled in the floodplain.

Filling - General

1. Filling (dredge disposal, gravel pad and road construction, and gravel island building) should be avoided in highly sensitive fish and wildlife habitats (see Map E).

2. Activities which are likely to require filling, such as the construction of near shore facilities and onshore pipeline routes, should be sited where minimal dredging and filling would be required.

3. Detailed plans for filling operations should be submitted to resource management agencies well in advance of proposed activities so that permitting delays can be eliminated and site specific mitigating measures may be developed to protect local fish and wildlife resources from unnecessary impacts.

4. Filling activities should be scheduled to avoid breeding periods and other critical life history phases of sensitive species (see Table_28_).

5. Easily erodable material (i.e. silt) should not be used for construction of offshore facilities in Norton Sound. The grain size of these materials is too small to withstand ocean currents and waves and are likely to result in increased water turbidity and burial of downstream habitats.

6. Because of the scarcity of gravel in Norton Sound, quarry rock and alternate materials should be used for construction whenever possible.

7. Solid fill structures such as gravel islands and causeways should not be located in areas where they will disrupt local

circulation patterns, adversely affect water quality, or interfere with fish or marine mammal migrations.

8. Do not construct long continuous fill causeways or docks. Use piling structures or provide sufficient breaches to allow normal fish passage, and for maintenance of water quality.

9. Use fill material compatible with the area. In areas where there is a high ambient silt level such as the Yukon River Delta, silt may be acceptable for structures. In areas with low turbidity - use only clean material and armor to prevent erosion and siltation.

Dredge Disposal

1. When the spoil removed in a dredging operation is compatible with existing material (i.e. mud on mud, sand on sand), direct disposal of the dredge spoil onto the bottom may be acceptable. However, the spoil should not contain toxic pollutants, should spread in a thin layer (less than two inches) which will allow marine organisms to burrow through it, should not be deposited in ridges that significantly impede water flow, and should not cover vital habitat areas, i.e., wetlands, tideflats, estuarine waters, productive benthic habitats or *Fucus* and eelgrass beds.

2. In some areas, littoral zone disposal of material dredged from rivers or nearshore channels may be required if deep water disposal would create a deficit budget in longshore sediment transport. Such disposal should be planned to avoid impacts to sensitive species and habitats.

3. Dredged material should not be deposited in wetlands, but rather in a designated area where there will be a minimum of environmental alteration.

4. Dredged material should be disposed of at a sufficient distance inland to prevent reintroduction of the materials into the waterway.

5. In water depths in excess of 2 meters (6.5 feet), water column turbidity can be reduced by vertically discharging the dredged slurry through a diffuser (a 90-degree elbow) at a depth of 0.5 to 1 meter below the water surface. Use of a diffuser minimizes areal coverage over the disposal area but maximizes mounding of the fluid mud and dredged material. The simple open-ended pipeline, discharging above and parallel to the water surface, creates the greatest water column turbitity but produces a relatively thin, widespread fluid mud layer.

Gravel Pad and Road Construction

1. Gravel pads and roads should not be contructed in vital fish and wildlife habitats.

2. All linear gravel structures, such as roads and construction pads, should be adequately culverted to prevent artificial ponding or water starvation.

3. Facilities and associated developments should be designed to reduce number and size of pads needed and the amount of gravel needed.

4. Avoid building pads, especially roads, near waterways to lessen erosion potential.

5. Pads and roads should be of sufficient thickness to prevent permafrost melting. Artificial insulation should be incorporated in fill to reduce gravel requirements.

6. Berms and drainage ditches in non permafrost areas should be installed to control the rate of runoff from unvegetated surfaces.

7. Pads should be built in such a way that drainage patterns in surrounding areas will not be altered.

8. Dust should be controlled on pads by watering, not oiling. Dust accumulation on snow and vegetation leads to accelerated spring snow melt and vegetation changes.

9. Roads across wetlands or wet tundra should be aligned perpendicular to the direction of sheet flow.

Gravel Islands

1. Vital fish and wildlife habitats should be avoided as sites for gravel islands.

2. Construction of gravel islands should be scheduled to avoid breeding periods, migrations, and other critical life history stages.

3. Barge routes for transportation of material to construction site should be planned to avoid marine mammal and bird concentrations. Bubbles from the barges wake can persist for several hours, causing a "behavioral" barrier to migratory movements and barge traffic disrupts resting and feeding birds.

4. To reduce turbidity and siltation, use of coarse-grained gravel is preferred over use of fine-grained construction materials such as silt, sand, and in some cases gravel.

5. Shorelines of artificial islands should be protected from erosion using the methods found in the Shoreline Alteration section of this report. Erosion can cause siltation and environmental damage to downdrift areas as well as necessitating continual replenishment of eroded material.

6. Caisson retained islands require less gravel fill, can be moved, and should be considered for use during exploration and production drilling over solid fill gravel islands.

7. Gravel islands should not be sited in locations where significant interference with local circulation and subsequent changes in salinity, temperature, and sediment transport may occur.

HIGH SENSITIVITY AREAS

The designation of high sensitivity was given to areas where the impacts of dredging and filling, gravel mining, and gravel islands would be extermely adverse to fish and wildlife populations in the northern Bering Sea-Norton Sound region. Adverse impacts would result in reduced populations of fish and wildlife that are of commercial, recreational, and subsistence importance. The following areas have been indentified as having a high sensitivity to dredging and filling;

1. Eelgrass beds
2. Highly productive and heavily used wetlands and tideflats and wetlands and tideflats where productivity is not known
3. Estuaries and lagoons
4. Salmon streams
5. Herring spawning areas
6. Sheefish and whitefish streams
7. Seabird colonies
8. Waterfowl and shorebird nesting and staging areas, including: major and important waterfowl staging areas, emperor geese molting and staging areas, snow geese staging areas, swan nesting/use areas, sandhill crane use areas, shorebird fall staging areas and important habitat.
9. Waterfowl and shorebird spring concentration areas
10. Peregrine falcon nesting/use areas
11. Marine mammal haulouts including recurrent and occasional walrus haulouts, spotted seal haulouts and feeding areas, and sea lion haulouts

12. Subsistence freshwater mussel harvest areas

In order to protect fish and wildlife values, dredging and filling activities, gravel mining and building of gravel islands should not occur in high sensitivity areas.

TABLE 28 : MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND SPECIES, HABITATS OR HARVEST ACTIVITIES ARE MOST SENSITIVE TO DREDGING AND FILLING, GRAVEL MINING AND GRAVEL ISLANDS.

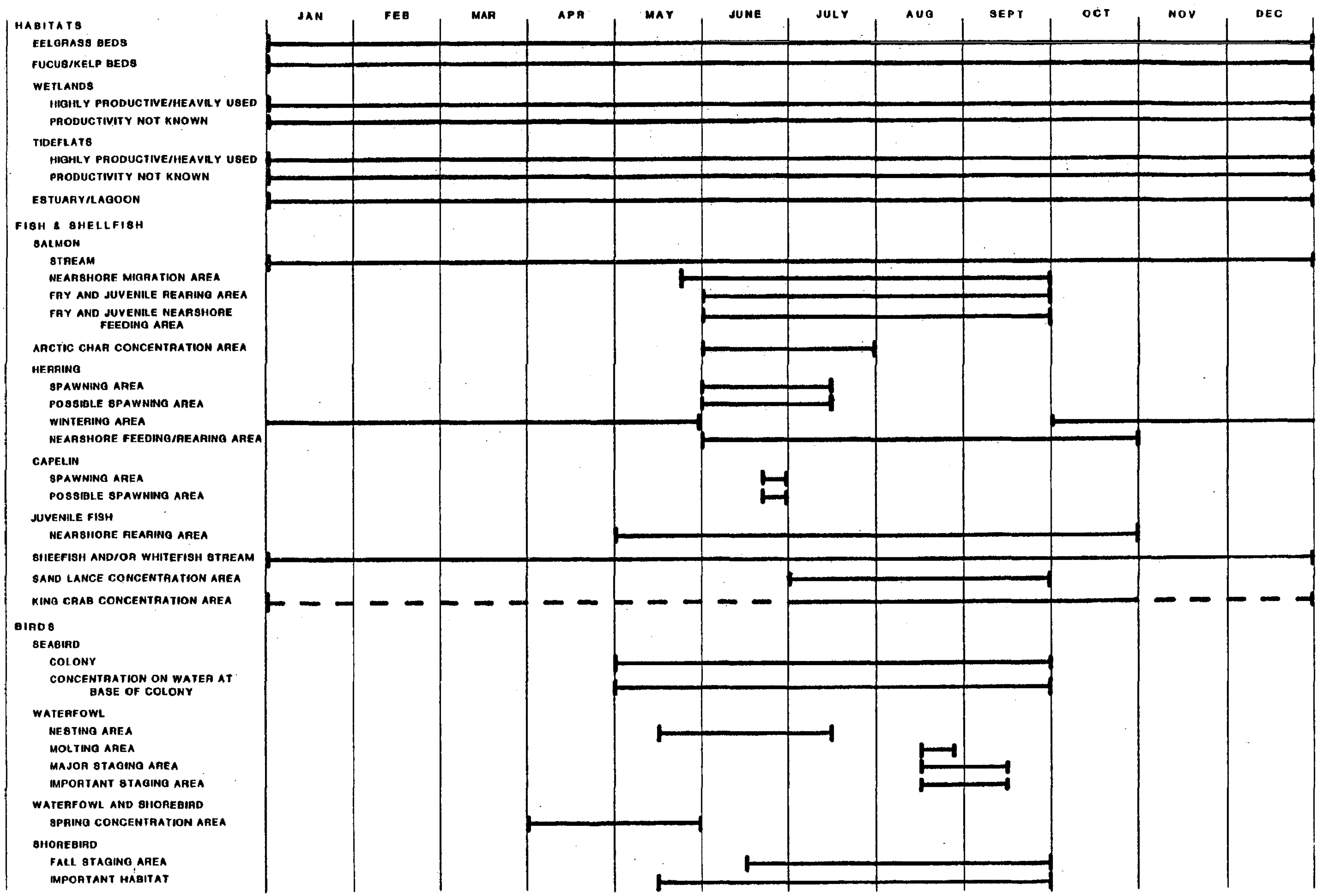
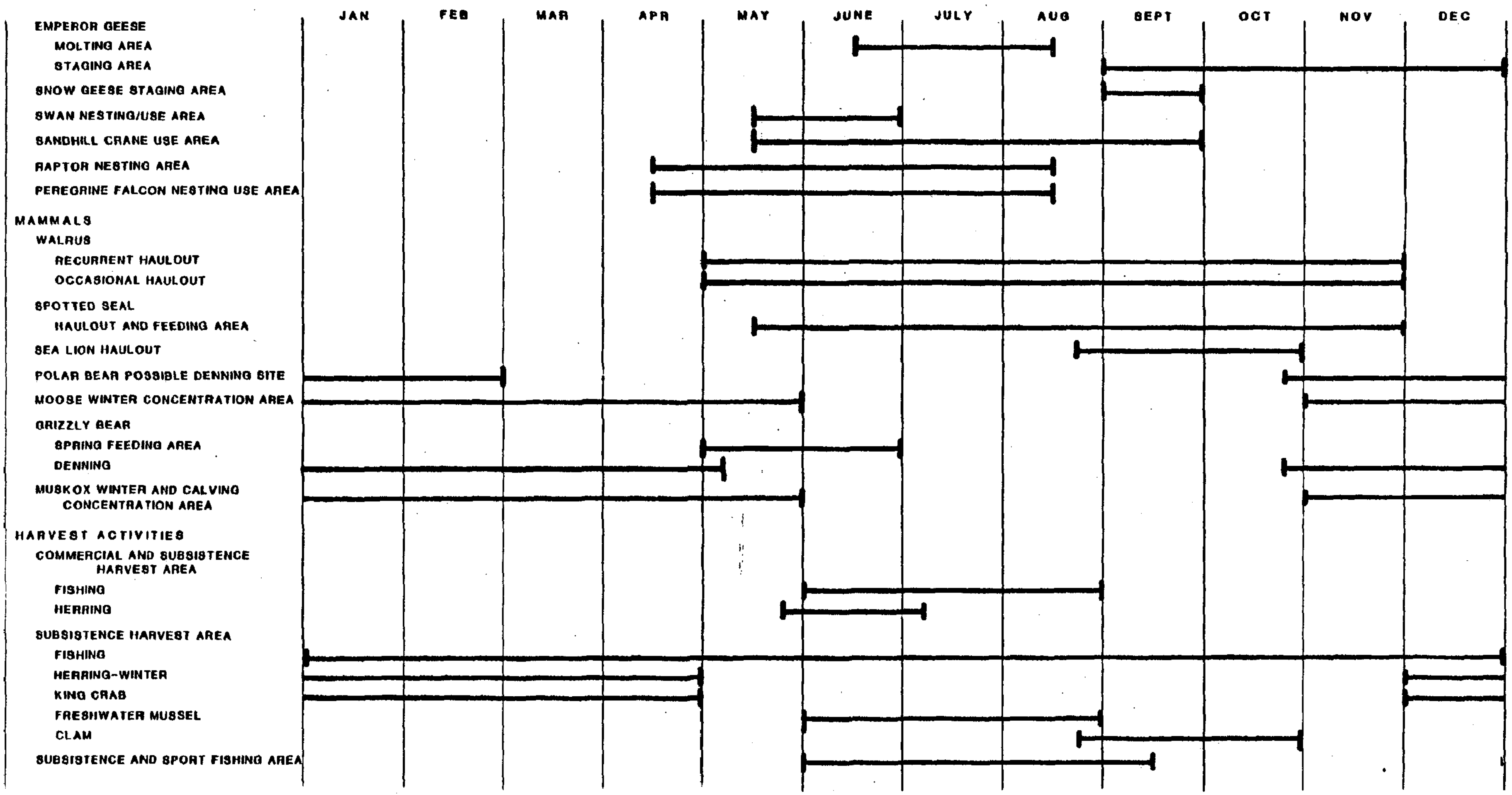


TABLE 28 : (CONT.) MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND SPECIES, HABITATS OR HARVEST ACTIVITIES ARE MOST SENSITIVE TO DREDGING AND FILLING, GRAVEL MINING AND GRAVEL ISLANDS.



F

SHORELINE ALTERATION

SHORELINE ALTERATION

Sources and Biological Effects

The exploration, development, production and transportation of hydrocarbons in the Norton Basin will require the construction of facilities along the shoreline. Some of these structures provide access or transportation between land and sea while others are built to prevent the erosion of the coastline or to provide new onshore construction sites (ASPO, 1978). Pipelines are built to connect offshore production platforms to onshore facilities and their landfalls are located along the shoreline. Typical shoreline structures include bulkheads, riprap, groins, jetties, breakwaters, causeways, piers, docks, and bridges (Shanks, undated). Construction of these structures may alter the shoreline and damage the habitat of coastal fish and game resources. Poorly designed and improperly placed structures can disrupt the transportation of shoreline sediments and alter tidal circulation. The effects of individual projects on fish and wildlife resources may not be significant, but shoreline alteration, proceeding one project at a time, can ultimately alter or destroy the entire natural shoreline of a coastal system (Shanks, 1978)

Changes in coastal habitats occur when shoreline structures are improperly designed and sited. Tidal action may be inhibited leading to altered water circulation patterns and changes in water temperatures and salinity (ASPO, 1978; Shanks undated). Structures built in vital habitat areas such as wetlands may destroy important nesting bird habitat. Fish migration routes may be changed and spawning areas destroyed. Structures built perpendicularly to the coastline impede or disrupt nearshore nutrient flow and sediment transport. The rapid changes in erosion and deposition which occur cause the alteration and destruction of benthic habitat which may result in a change in the number and variety of species using that habitat.

The actual construction of shoreline structures also causes adverse environmental impacts. Dredging and filling both result in habitat destruction and the suspension of bottom sediments. Turbidity, caused by the suspension of sediments, reduces primary production and lowers oxygen levels. As the sediment settles out, benthic organisms may be smothered (Cronin et al, 1978; Clark and Terrell, 1978). Suspended sediments may also interfere with the respiratory and feeding mechanisms of fish, zooplankton, and benthic organisms. Construction activities cause other environmental impacts such as water pollution, air pollution, and noise and disturbance (Shanks, undated).

Breakwaters, groins, jetties, and other structures built perpendicular to the coastline disrupt the flow of nutrients along the shoreline and inhibit the transport of sediment by wave action and longshore currents. The natural sediment balance is disrupted, causing sand and other fine-grained material to build up on one side of the barrier while the shoreline on the other side is starved and erodes away (Carrol, undated). The lee side of coastal structures can experience degradation of water quality, fluctuations of temperature and salinity, and a longer period of ice cover because of lower wave energy and altered current patterns. (Mulvihill et al. 1980; U.S. Army Engineer District, Buffalo, 1975).

The presence of jetties at a river or bay mouth alters both river outflow and tidal currents affecting habitats well into the river or bay (Mulvihill et al., 1980). Jetties can also limit or alter the movement of fish and crustaceans into and out of estuaries (Cronin et al., 1971). Breakwaters have been shown to affect longshore fish migration routes (Shanks, undated). Stockley (1974) found that the presence of a shore-connected breakwater extending into deep water interrupted the shallow water migration routes of salmon fry. The fry were subject to increased predation because they would not migrate around the breakwater and were forced to concentrate in one area (Shanks, undated).

Coastal bulkheads and riprap, constructed to inhibit erosion for one particular project, may result in the loss of adjacent coastal marshes and other vital habitats of fish and wildlife (Clark and Terrell, 1978). The destruction of coastal wetlands eliminates feeding, nesting, resting, and nursery areas of birds and small mammals (Mulvihill et al., 1980). The algaes and detritus from these wetlands, which comprise an important food source for shellfish, zooplankton, and benthic organisms, will be lost. Bulkheads that extend into water areas alter circulation patterns and increase scouring of bottom sediments therefore changing vital habitats such as shellfish beds and tideflats (Clark and Terrell, 1978). The newly created deep water zone in front of a bulkhead often has a lower concentration of detritus, lower phytoplankton production, and fewer benthic organisms than adjacent unbulkheaded areas. The turbulence and scouring action in front of bulkheads from reflected wave energy often prohibits vegetation from reestablishing and may destroy existing grass flats. Bulkheads extending down below the mean high waterline were found to bury and destroy smelt spawning substrate in upper intertidal and sand-fine gravel beach areas in Puget Sound (Mullvihill et al., 1980). The reduction of shallow water areas in front of bulkheads forces rearing salmon fry to either move out into deeper waters or concentrate near the structure. Both situations make salmon fry more vulnerable to predation and reduces their survival rate. Stair step design bulkheads or riprap revetments with less than a 45° slope provide more protective habitat for salmon fry than vertical bulkheads (Heiser and Finn, 1970; Shanks, undated).

Industrial development and the secondary development and population growth resulting from oil and gas development, may create a need for new and improved coastal roadways to serve industrial sites. The construction of new roads in previously undeveloped areas may destroy significant amounts of important fish and wildlife habitat. New roads will also create additional access to fish and wildlife resources, and may increase harvest pressure.

Road construction across coastal wetlands and streams is of particular concern since improperly constructed bridges, culverts, pads, causeways, and other coastal structures can alter circulation and drainage patterns, current velocities, tidal movements, and salinity patterns. Solid fill causeways across coastal wetlands act as dams, dividing the saltmarsh into freshwater and saline components. Marsh vegetation will be adversely affected, reducing the amount of plant biomass and the value of the wetlands as wildlife habitat (Sipple, 1974 in Shanks, undated). Piling structures, which allow the free movement of sediments and aquatic life, have minimal effect on fish and wildlife resources.

The logistic support required for offshore oil development may necessitate the building of small boat harbors. Calm water within a harbor leads to water quality problems including oxygen depletion, chronic discharge of hydrocarbons, and the buildup of toxic metals from the chipping of lead based paint and erosion of zinc electrolysis plates. Reduced water circulation can cause an accmumlation of organic substances and a decrease in oxygen levels (Shank, undated). A study by Reish (1963) showed that populations of benthic organisms decreased within one year after construction of the Alamito Bay Marina. He concluded that this decline resulted from limited water circulation and a decline in water quality (Shanks, undated). The construction of harbors can be especially harmful to an ecosystem if they are built in important spawning and nursery areas or in wetlands (Shanks, undated).

Because the northern Bering Sea-Norton Sound region is shallow and experiences severe ice conditions during the winter, tanker terminals and loading docks will probably be sited at the end of long solid-fill causeways or on man-made offshore islands. Impacts resulting from solid fill causeways are similar to those resulting from breakwaters and jetties, and include: changes in circulation, nutrient flow and longshore sediment transport; and blockage or alteration of fish and marine mammals migration patterns. Culverts and breaches designed into causeways for fish passage may actually prevent passage if not planned carefully.

Increases in water level on one side of the structure (either from wind or tidal action) can create high current velocities in the culvert or breach that can prevent passage of small fish or cause them to become exhausted and more vulnerable to predation (U.S. Army Corps of Engineers, Alaska District, 1980; Brett, 1958). Man-made or artificial islands can alter circulation patterns and lead to increased sedimentation in downdrift areas from erosion of material used in building the island. Other impacts of artificial islands are addressed in the Dredging and Filling, Gravel Mining, and Gravel Islands section.

Table 29 Effects of shoreline alteration on fish, wildlife, aquatic plants and their habitats

Species/Habitat	References	Type of Study	Type of Structure	Effect and Evaluation
BIRDS	Mulvihill et al., 1980	literature review	breakwaters	Breakwaters can create new bird habitat. The stone surface upon and behind the breakwater may be used by birds. If sand deposition creates an emergent or intertidal sandbar, gulls, terns, and other beach dwelling species may utilize it. Colonial nesting may occur on the breakwater if human disturbance is limited during the nesting season.
FISH				
Salmon (*Oncorhynchus* sp.)	Heiser & Finn, 1970	field observation	bulkheads, revetments	Vertical bulkheads cause an abrupt habitat change from land to deep water with few shallow water areas. Salmon fry tend either to go out into deeper water when confronted with a bulkhead or to concentrate near bulkheads and not go around them. Both circumstances make salmon fry extremely vulnerable to predation. Stair step design bulkheads or riprap revetments on a 45° or less angle were found to provide protective habitat for salmon fry.
Salmon (*Oncorhynchus* sp.)	McKinley & Webb, 1956	culvert standards	culverts	To facilitate fish passage, a culvert grade should not exceed one-half of one percent and the invert (bottom) of the culvert at the outfall should be one-half foot below the stream bed. Common types of culverts which interfere with fish passage are ones which have a steep slope or ones in which the outfall is above the stream bed. Steep slopes cause excessive velocities and shallow depths at normal and low flows. An invert above the stream bed soon causes erosion in the stream bed -- in certain instances, lowering the stream bed immediately below the culvert by as much as 12 feet. When carried to the extreme, these conditions will result in the complete blockage of migratory fish. Even when not extreme, they may delay the fish and thus interfere with spawning.
Atlantic Salmon (*Salmo salar*)	Clay, 1961	design criteria	man-made obstructions	To provide passage of Atlantic salmon through man-made obstructions, the following criteria were adopted: 1. an attraction flow so entrance to structure can be located by fish, 2. an absolute minimum depth of two feet, 3. a minimum velocity of four feet per sec., 4. a maximum velocity of eight feet per sec.,
Coho Salmon (*Oncorhynchus kisutch*) Sockeye Salmon (*Oncorhynchus nerka*)	Brett et ak., 1958	laboratory & field observation	areas of increased waterfowl	Underyearling coho salmon (length 5.4 cm) maintained a maximum cruising rate of (30 cm/sec.) 1.0 ft per sec. at an optimum temperature of 20°C, and were depressed to (6 cm/sec.) 0.2 ft per sec by a temperature approaching 0°C. By comparison, underyearling sockeye salmon (6.9 cm) of the same average age showed a maximum of (35 cm/sec) 1.1 ft per sec at an optimum temperature of 16°C and a minimum of approximately (12 cm/sec.) 0.4 ft per sec.

Species/Habitat	References	Type of Study	Type of Structure	Effect and Evaluation
				The cruising speed is that rate which a fish can maintain for a minimum period of one hour under strong stimulus. Initial bursts of speed of up to (about 1.4 m/sec) 4 to 5 ft/per sec were observed. These darts were only 0.6 to 0.9 m (2 to 3 ft) in length and were followed by a "slump" in performance. The authors believe this slump is caused by an overtaxing of the respiratory system and a slight oxygen debt.
Arctic Grayling (*Thymallus arcticus*)	MacPhee and Watts, 1976	direct observation	culverts	Test results showed that to permit 75% passage of grayling through 18.3 m (60 ft) and 30.5 m (100) diameter culverts, the flow velocity must be restricted to 5.0 and 3.5 times the fork length respectively. Only 25% of the fish were able to ascend the culverts when the velocity was 6.2 times the fork length in the 18.3 m culvert and 4.0 times the fork length in the 30.5 m culvert. No fish smaller than 87 mm were tested.
Arctic Grayling (*Thymallus arcticus*)	Tack and Fisher, 1977	field observation	model A Alaska fish ladder	Usage of a fish ladder by adult and juvenile grayling increased with increased water velocities to the maximum velocity tested (2.6 fps). The increased flow apparently increased attraction. Yearling grayling (under 130 mm fork length) were inhibited in their passage at flows above 2 fps. Increasing slope also had an attractive effect for adult and juvenile grayling, and also yearlings, up to the point that water velocities prevented their passage. Highest success rates at any flow tested were 100% for adults, 94% for juveniles, & 38% for yearlings.
Surf Smelt	Millikan et al., 1974	field observation	bulkheads	Bulkheads extending below the mean high waterline were found to bury and destroy smelt spawning substrate in upper intertidal and sand-fine gravel beach areas in Puget Sound.
Fish	Tetra Tech, 1980	feasibility study	causeway	A study into the feasibility of constructing a causeway at Nome concluded that a shore connected, filled causeway would divert longshore fish movements, and could impact anadramous fisheries by creating high siltation levels during dredging and filling (construction and maintenance). The causeway could also cause changes in nutrient circulation and benthic habitat as a result of altered littoral regimes, and would cause major habitat alterations in the local nearshore environment.
SHELLFISH AND BENTHOS				
Shrimp	Mulvihill et al., 1980	literature review	bulkheads	Studies of shrimp in bulkheaded and natural estuarine habitats have shown natural areas to be more productive. These differences were attributed to low abundance of organic detritus and benthic macro-invertebrates, deeper water, and loss of intertidal vegetation in bulkheaded areas.
Clams	Ellifrit et al., 1972	field observation	bulkheads	Clam populations in natural and bulkheaded areas in Hood Canal, Washington were studied. Twice as many clams were found on natural beaches at three out of the four sites studied. At two sites significantly more Japanese littleneck clams, *Venerupis*

Species/Habitat	References	Type of Study	Type of Structure	Effect and Evaluation
				japonica, were found in upper intertidal regions. Differences in size and distribution were noted. Clams in the lower intertidal regions appeared unaffected by bulkheads. The authors concluded that these differences probably were due to changes in current patterns associated with bulkheads. Bulkheads appeared to produce less favorable conditions for settling and survival of clam larvae and may have caused reduction in availability of nutrients and food.
Oysters	Mulvihill et al., 1980	literature review	jetties	A jetty's influence on littoral transport contributed to the breaching of a sand spit. This allowed sand and boulders to enter a protected lagoon and bury commercial oyster beds.
Oysters	Moore and Trent, 1971	field observations	bulkheads	Settling, growth, and mortality of oysters was studied at two bays in West Texas. The first area was a dead end canal that had been created by dredging, bulkheading, and filling of a coastal marsh. The second area was a dead end bayou in an unaltered part of the same marsh. The settling of oysters was 14 times greater in the natural marsh than in the canal area. Faster growth rates and lower annual mortality rates characterized oysters in the natural marsh. The authors attributed these differences to the poor water circulation, plankton blooms, low levels of dissolved oxygen, and high nutrient levels in the canals.
Benthos	Mulvihill et al., 1980	literature review	groins	The accretion of sand behind groins buries those bottom organisms which cannot move away. However, this disadvantage is usually offset by the increased sand surface area provided.
PLANTS				
Phytoplankton, Vegetation	Mulvihill et al., 1980	literature review	bulkheads	The newly created deep water zone in front of a bulkhead often has a lower concentration of detritus, lower phytoplankton production, and fewer benthic organisms than adjacent unbulkheaded areas. In addition, the turbulence and scouring action in front of bulkheads from reflected wave energy often prohibits vegetation from reestablishing and may destroy existing grass flats.
OTHER EFFECTS ON SPECIES				
Fish, Crustaceans	Cronin et al., 1971	literature review	jetties	Jetties may limit or alter movement of fish and crustaceans into and out of estuaries.
Marine Invertebrates, Fish	Mulvihill et al., 1980	literature review	floating breakwater	Floating breakwaters can attract marine organisms. In Florida, a community of marine invertebrates and fish was well established on a floating breakwater within a month of its placement.
Marine Species	Mulvihill et al., 1980	literature review	revetments	Construction of a revetment, a sloping structure built to protect existing land or newly created embankments against erosion by wave action, buries existing flora and fauna but provides new and different substrate. The diversity and abundance of organisms living in and around the revetment varies depending on type of facing, energy conditions, and its location on the beach. A man made island in California which was protected by rock and tetrapod revetments, supported 225 species of plants and animals while a sandy mainland shore 1/2 mile distant had fewer than 12 species.

Species/Habitat	Reference	Type of Study	Structure	Effect and Evaluation
Species Composition	Mulvihill et al., 1980	literature review	breakwaters	Breakwaters constructed from rock, rubble, and other materials with irregular surfaces provide a rocky surf habitat on the seaward side, and a rocky calm habitat on the lee side. These new habitats are gained at the cost of the previously existing bottom dwelling organisms. In many situations, the new rocky habitat can be considerably more productive than the substrate that previously existed. Changes in species composition can also occur because of altered fluctuations of temperature, salinity, and water level in the protected waters inside a fixed breakwater.
HABITATS AND PHYSICAL PROCESSES				
Wetlands	Mulvihill et al., 1980	literature review	bulkheads	Bulkheads and revetments can affect the plant and animal communities in the upper foreshore and backshore zones. Bulkheads, constructed in wetland areas, can cause extensive damage to fish and wildlife habitat. Construction and associated backfilling destroy wetlands by covering up narrow fringe marshes, by covering up the waterfront edge, and by altering water circulation in larger shorefront marshes. Destruction of shorefront wetlands eliminates waterfowl feeding, nesting, and resting habitats and can destroy habitat of other birds and small mammals.
Estuaries	Mulvihill et al., 1980	environmental impact statement	jetties	The presence of jetties at a river or bay mouth alters both river outflow and tidal currents. These alterations are often felt well into the estuary and may have widespread effects. Altered rates of nutrient and sediment accumulation can occur in salt marshes. Salinity and temperature changes can occur. The tidal prism can be altered since overall circulation patterns within an estuary are affected by the change in water flow through a stabilized channel. The flushing characteristics of the estuary can be changed and wave height is often increased in its lower regions.
Nearshore Areas	Shanks, 1978	literature review	breakwaters	Breakwaters (1) Scour at the base because of wave energy that is deflected downward. Scour depth at the toe of a bulkhead may be up to twice the height of the average wave striking the structure. (2) May deflect wave energy (erosion forces) to adjacent properties, increasing their erosion. (3) Can accumulate debris at the ends of the structure and in sharp corners. (4) Tend to be straight, rather than following natural shorelines.
Nearshore Areas	Shanks, 1978	literature review	groins	Characteristics of groins include: (1) groin surfaces serve as an attachment site for aquatic organisms (2) groins often provide a protected area for the establishment of beach vegetation (3) accretion of sand behind groins bury bottom-dwelling organisms in the area (4) in general, the length of the protected shoreline equals twice the length of the groin (5) placement of one groin often leads to the need for another some distance downdrift of the first, because groins tend to accelerate downdrift beach erosion by reducing littoral drift and (6) downdrift beaches will recede until the groins are filled and drifting sand can bypass the structures.

Habitats/Physical Processes	References	Type of Study	Type of Structure	Effect and Evaluation
Tideflats Circulation Patterns Shellfish beds	Mulvihill et al., 1980	literature review	bulkheads	Bulkheads that extend into water areas alter circulation patterns and increase scouring of bottom sediments therefore changing vital habitats such as shellfish beds and tideflats.
Nearshore Circulation, Littoral Transport	Mulvihill et al., 1980	literature review	breakwaters	A fixed breakwater can cause piling-up of water behind it, decrease circulation, interfere with tides and currents, and obstruct littoral drift. If the breakwater is shore-connected, particularly if it has a shore-parallel leg, the effect on littoral drift can be severe. Piling-up most frequently occurs behind breakwaters that have restricted openings. This leads to a higher water level behind the breakwaters than outside. Differences in the water levels result in accelerated flows at the openings or ends of the breakwater.
Shoreline Erosion Desposition, Littoral Transport	Mulvihill et al., 1980	literature review	breakwaters	Sand tends to be deposited on the shoreline opposite a detached, fixed breakwater and immediately can form a tombolo (a bar or spit that connects an island with the shore) between the structure and the shore if the breakwater is long enough in proportion updrift of a shore-connected structure. The sand deposition opposite a detached, fixed breakwater to its distance from the shore. If conditions are not conducive to tombolo formation, detached, fixed breakwaters can still cause spit formation on the opposite shoreline. This spit then acts as a partial barrier to littoral drift, allowing the sand to deposit updrift and be eroded away downdrift. Floating breakwaters have much less influence on littoral drift.
Water Quality	Mulvihill et al., 1980	literature review	breakwaters	Because of lower wave energy and altered current patterns, the lee side of a fixed breakwater can experience degradation of water quality and fluctuations of temperature and salinity.
Benthic Habitat	Mulvihill et al., 1980	literature review	seawalls	Structures which are not vertical and have rougher faces, such as revetments or stepped concrete seawalls, tend to reflect less wave energy seaward and are less affected by toe scour.
Nearshore Habitats	U.S. Army Corps of Engineers, Seattle District, 1971			Construction activities (rock dumping, jetting piles, and dredging to a solid base) associated with the building of shoreline structures can disturb bottom sediments, increase turbidity, and impact bottom dwelling organisms.
Littoral Transport	Carroll, undated	literature survey	perpendicular shoreline structures	Structures built perpendicular to the coastline disrupt the flow of nutrients along the shoreline and inhibit the transport of sand by wave action. The natural sediment balance is disrupted causing sand to build up on one side of the barrier while the beach on the other side is starved for sand and erodes away.
Circulation Patterns, Migration Fish	U.S. Army Corps of Engineers, Alaska District, 1980	DEIS	causeway	Effects of the proposed causeway for the Prudhoe Bay Waterflood Project include: alteration of natural circulation patterns and possible nutrient flow into nearby Simpson Lagoon, and delay of fish migration.

Habitats/Physical Processes	References	Type of Study	Type of Structure	Effect and Evaluation
Littoral Transport	Mulvihill et al., 1980	literature review	jetties	In nearshore areas the most significant effect of jetties is alteration of littoral transport. Sand is impounded updrift and eroded downdrift. If a single jetty is installed at a river or harbor entrance, the opposite shore can be severely eroded. Additionally, a shoal can form at the end of a single jetty updrift of an inlet. The inlet will eventually be filled in.
Littoral Transport Marsh, Circulation	Mulvihill et al., 1980	literature review	causeways	The most prominent chronic effects of bridges and causeways mentioned in the literature are an alteration in current, velocity, and water circulation patterns. Salinity may be affected in estuarine environments and other areas subject to tidal flow. Marsh circulation may also be affected. Concomitant alterations in the flora and fauna are dependent on the degree of salinity change. Blocking of longshore currents and sedimentation may result from causeways.
Littoral Transport	Mulvihill et al., 1980	literature review	groins	Downdrift beach starvation results when groins completely obstruct littoral drift. Downdrift beaches will recede until the groins are filled and sand bypassing occurs. If groins are used to widen beaches, they can be filled with sand after construction thereby lessening the potential impact downdrift. Scour can also occur on the leeside of groins. This can often be minimized by including weirs along the length of a groin or by making the structure permeable.
Wetlands, Circulation	Mulvihill et al., 1980	literature review	groins	Circulation patterns in Chesapeake Bay were altered by groin placement. The altered circulation affected erosion patterns as well as nutrient and sediment accumulation rates in adjacent marshes.
Littoral Transport	Coast Plains Center for Marine Development Service, 1973	unknown	floating piers	Floating piers can affect beach sand movement. Open pile piers are recommended in areas of significant littoral transport and longshore currents.
Ice	U.S. Army Corps of Engineers Buffalo District, 1975	EIS	breakwaters	In the Great Lakes region, protected water behind breakwaters ices over earlier and remains frozen longer in the spring than water not so protected.

Sensitivity of Areas and Recommended Mitigative Measures

Areas in the northern Bering Sea and Norton Sound were ranked as having moderate or high sensitivity to the impacts of shoreline alteration (see Map F). These designations were based on available data and were made after evaluating the following criteria:

1. The sensitivity of each fish and wildlife species or habitat to shoreline alteration.

2. The sensitivity of each species to shoreline alteration which is experienced during the various stages of its life history.

3. The time of year that these critical life history stages occur and the period during which each species would be most affected by shoreline alteration.

4. The location of habitats where critical life history stages occur.

5. The productivity of the habitat.

6. The uniqueness of the habitat.

7. The species' population numbers and relative importance of the population.

8. The degree to which the impacts of shoreline alteration could be mitigated.

Specific considerations and assumptions that were made during the course of ranking included:

1. Impacts of shoreline alteration would be greatest in eelgrass beds, wetlands, tideflats, and lagoons. These habitats are generally highly productive areas that are highly susceptible to changes in circulation and longshore sediment transport.

2. Fucus/kelp beds, although highly productive habitats which would be affected by changes in circulation and longshore transport, were not ranked in the high sensitivity category due to their abundance in eastern Norton Sound. Herring spawning areas (Fucus is the primary spawn substrate) were ranked as high sensitivity and those Fucus beds within spawning areas will be afforded the protection of the higher sensitivity designation.

3. Species most affected by shoreline alteration are those whose critical habitat would be destroyed by coastal structures (haulout areas used by walrus, spotted seals, and sea lions, and herring spawning areas) or altered by changes in circulation, or depth (nearshore fish migration routes and rearing areas and areas of first open water in the spring which are used by arriving waterfowl and seabirds).

4. Herring spawning areas and the mouths of salmon streams were ranked as highly sensitive to shoreline alteration. Loss of spawning habitat and interference with migration into spawning streams would have an adverse affect on these important commercial and subsistence species.

5. Seabird concentration areas in marine waters at the base of seabird colonies and waterfowl or shorebird spring concentration areas were ranked as high sensitivity areas based on a report of shoreline structures (such as breakwaters) delaying breakup (see impact section - U.S. Engineer District Buffalo 1975). Late breakup in these important early spring use areas would have adverse impacts on seabird, waterfowl, and shorebird populations.

6. Subsistence clam harvest areas were ranked as highly sensitive to disturbance because altered circulation and longshore sediment transport patterns in the vicinity of clam beds will have adverse affects on the productivity of these beds.

7. All nearshore critical habitats of important fish species (except herring spawning areas and the mouths of anadromous fish streams) were ranked as moderately sensitive. It was felt that most adverse impacts of shoreline structures could be minimized by following specific environmental guidelines.

8. Waterfowl nesting and staging areas were ranked as moderately sensitive because changes in circulation and longshore sediment transport caused by coastal structures, and changes in drainage patterns caused by the building of coastal roads, would alter the wetland habitats critical for these life history stages.

9. Belukha whale and gray whale nearshore feeding areas were ranked as moderately sensitive because large coastal structures could alter nearshore movements of these species or their food species.

10. Coastal structures should be built according to specific environmental stipulations (see mitigative measures) in any nearshore subsistence or commercial fishing area.

11. Low sensitivity designations were not applied to any area of the coastline. Although specific data is not available for all areas of the Norton Sound and St. Lawrence Island shorelines, general life histories for fish species inhabiting the northern Bering Sea-Norton Sound region decribe the importance of nearshore habitats for feeding, rearing, and spawning. Until more specific data is available coastal structures in Norton Sound and on St. Lawrence Island should be built according to specific environmental guidelines (see mitigative measures).

Sensitivity Designations and Mitigative Measures

LOW SENSITIVITY AREAS

Areas of low sensitivity were not designated because it was felt that the placement of shoreline structures anywhere along the coastline would adversely affect coastal productivity and, therefore, any shoreline alteration should be undertaken according to guidelines discussed in the Mitigative Measures.

MODERATE SENSITIVITY AREAS

Areas of moderate sensitivity were defined as those areas along the coastline where the effects of shoreline alteration could be prevented, minimized, or ameliorated. Habitats included in the moderate sensitivity area include:

1. *Fucus*/kelp beds
2. Salmon nearshore migration areas and juvenile and fry nearshore feeding and rearing areas
3. Arctic char and sand lance concentration areas
4. Herring nearshore feeding/rearing areas and possible spawning areas
5. Capelin spawning areas and possible spawning areas
6. Juvenile fish nearshore rearing areas
7. Waterfowl and shorebirds nesting and staging areas including: major and important waterfowl staging areas, emperor geese molting and staging areas, snow geese staging areas, swan nesting/use areas, sandhill crane use areas, and shorebird fall staging areas and important habitat

8. Grizzly bear spring feeding areas

9. Belukha whale and gray whale nearshore feeding areas

10. Commercial and subsistence fishing and herring harvest areas and subsistence fishing areas, king crab harvest areas, subsistence clam harvest areas, and winter herring harvest areas

Any shoreline alteration in areas of moderate sensitivity should be undertaken according to existing environmental regulations and the following guidelines:

General Mitigations

1. Structures that will alter the coast should not be built along the shoreline unless there are no alternatives.

2. Only water-dependent facilities should be placed along the coastline. All other facilities should be located inland if possible.

3. If coastal construction is necessary:

   a. structures should not be placed in vital coastal habitats such as wetlands, tideflats, estuaries, lagoons, or shellfish beds;

   b. natural drainage patterns of shorelands should not be altered. Channelization or diversion of coastal streams away from tideflats and wetlands can lead to increased pollution, altered salinity levels, and decreased biological productivity in estuarine waters;

c. coastal structures should not be built in intertidal and subtidal areas which provide valuable habitat for aquatic organisms;

d. channel erosion should be minimized by routing shipping into deeper channels and establishing speed limits;

e. construction activities should adhere to water quality standards and should be scheduled to avoid critical periods of breeding, feeding, and migration of coastal species;

f. large coastal structures should not be built in areas used for marine mammal harvest.

g. coastal structures should not be constructed in areas where rapid coastal erosion or deposition is occurring. Coastal engineering studies should be conducted as part of each project to identify these areas and to insure that construction will not aggravate the problem; and

h. during construction of coastal structures, turbidity should be kept to a minimum and turbidity control devices should be used when necessary.

Bulkheads

1. Bulkheading should be avoided by siting development away from eroding shorelines.

2. The construction of bulkheads to prevent coastal erosion should only be used when there is no alternative. Whenever possible use natural erosion protection such as planted marsh grasses rather than building bulkheads to minimize erosion on unstable shores or banks. Riprap causes less impact than bulkheads and should be a second choice for erosion prevention.

3. Bulkheads should not be built where they disrupt wetlands or other vital habitats such as clam beds. Even if bulkheads are not placed in vital areas such as estuaries, wetlands, or tideflats, they should be located far enough away to avoid altering sedimentation and water circulation in these important habitats.

4. Bulkheads should be placed inland from all wetlands. Bulkheads and similar structures used to prevent shoreline erosion in wetland areas should be built above the annual flood mark. Exceptions to this requirement may be made when bulkheads are constructed on shorelines which are devoid of vegetation or cannot be revegetated. Erosion is usually severe on unvegetated shorelines, thus requiring bulkheading for stablization. It is recommended that bulkheads built on unvegetated shorelines not extend outward from the mean low-water mark.

5. Bulkheads should not disrupt the outward flow of groundwater or runoff, and should be designed to be permeable to the

natural flow of both groundwater and runoff. Wooden bulkheads should be built with "weepholes" backed by filter screens to allow the passage of water through the structure.

6. In cases where bulkheads must be used, establishing a buffer strip of vegetation between the bulkhead and the water will protect coastal habitat and help reduce undermining of the bulkhead. When possible, existing shoreline vegetation should remain undisturbed.

7. Bulkheads should be designed so that reflected wave energy does not erode intertidal or subtidal areas.

8. Bulkheads should be constructed on a gently sloping shoreline rather than a steep one to reduce erosion.

9. During construction of bulkheads, it is generally desirable to drive supporting pilings in rather than jetting them in because jetting causes siltation and affects water quality. However, there may be instances (i.e., bird nesting) where the disturbance from pile driving may outweigh the effects of siltation, and jetting may be more desirable.

10. In appropriate cases, dredging should be done after the bulkhead is installed and then the area behind the bulkhead should be backfilled. This will prevent materials from slumping into the channel and will reduce the need for frequent maintenance dredging.

11. Fill material should not be excavated from shallow water and productive wetlands.

12. Riprap should be placed in front of a bulkhead to minimize its impacts on wave refraction and toe scour.

13. Bulkheads should not be constructed with sharp angle turns because this may create flushing or shoaling problems.

14. Vertically designed bulkheads (especially when they protrude to minus tide levels) should be avoided in salmon rearing areas. Stair-step design bulkheads or riprap revetments with a slope of less than 45° provide more protective habitat for salmon fry.

15. Bulkheads should be used only for erosion control and not to create real estate by filling. Do not use bulkheads for cosmetic purposes.

Riprap and Other Revetments

1. Armor unit revetments should be made of clean, non-polluting material. Any material contaminated with grease, phenol, lead, or other toxic elements should not be used.

2. Revetments with facings that are highly irregular (such as riprap) and have a shallow slope, have a greater ability to

support marine life and are preferred over steep-sided smooth revetments.

3. Riprap should be used rather than bulkheading wherever possible, although planting suitable vegetation to prevent erosion is more desirable than riprap.

4. When compared to bulkheads, riprap is more permeable to the flow of groundwater and runoff. The water can move unimpeded through the filter cloth and crushed rock backing of riprap structures. Other advantages of riprap are that it provides attachment for marine life, it can be built to conform to the natural configuration of the shoreline, and it is less expensive to build then most other erosion prevention structures.

<u>Breakwaters, Groins, and Jetties</u>

1. The use of groins to stabilize or widen beaches should be avoided if at all possible.

2. If groins are built the following recommendations should be followed to minimize the impacts:

    a. Place the shoreline end of the groin above the normal storm-tide line to prevent scouring.

b. Fill the area around the groin with sand, thus allowing drifting sand to bypass the groin and replenish downdrift eroded areas.

c. Place polyethylene mat (filter cloth) under the base of the groin to protect the structure from slumping due to erosion.

d. In some cases, excessive amounts of trapped sand can be mechanically transported around the groin to replenish eroding areas.

e. Groins which capture all littoral drift, thus encouraging or aggravating downbeach erosion, should not be constructed. Permeable groins or groins designed to include several weirs are preferable.

3. Dredging to bypass or remove accumulated sand from behind jetties should be scheduled for times of low productivity. Care should be taken in choice of downdrift sand release sites to avoid movement of sand into productive fish and shellfish areas or important plant communities.

4. Jetties should not be built at the mouths of productive anadromous fish streams. Changes in an inlet following construction of a jetty can affect runs of migratory fish.

5. In the construction of breakwaters, the use of riprap or dumped stone is biologically more desirable than breakwaters with flat faces since either of the former provides more habitat for aquatic species.

6. The base of breakwaters should be protected from erosion so that scouring does not affect structural integrity and, therefore, aquatic organisms in the area.

Piers and Docks

1. When utilities, pipelines and roads cannot be routed around vital habitats, they should be elevated on piers rather than placed on solid fill causeways.

2. Piers crossing marshy areas should be elevated high enough to avoid continual shading of the area under the piers.

3. Pilings should be driven in rather than jetted in. Jetting affects water quality in the construction area.

4. In marine and estuarine areas, construction of docking facilities on a series of ice resistant mono-pod type legs should be considered as an alternative to solid fill causeways.

5. Spacing of pilings should allow free flow of tidal currents and littoral drift.

Bridges and Causeways

1. The location of bridges and causeways should avoid vital habitat areas. Whenever possible these structures should be located upland away from wetlands and water basins.

2. Bridges or causeways built across water areas should be elevated on pilings to minimize the disruption of natural water flow and to avoid alteration of vital habitat areas. Solid fill causeways should be avoided.

3. When fill or abutments must be used in areas subject to flooding, they should be designed so that the floodwaters will not be raised more than 0.3 meters (1 ft) above the natural flood level.

4. Culverts should be sufficiently large, and enough culverts should be used, to permit a natural rate of water passage through solid-fill causeways. To provide adequate fish passage, culverts should protrude sufficiently above the water so that the entire passageway is well lighted and that water velocities do not exceed 0.5 fps under all tide and wind conditions.

5. Bridged breaches should be used in causeway design instead of culverts where tidal flow, littoral transport or fish migrations will be affected.

6. When building causeways or bridges in wetland areas, heavy equipment should be operated from the construction site (i.e., roadbed) rather than from the wetland area.

7. Environmental disturbances should be minimized during construction. Matting and/or vehicles designed to prevent soil compaction are recommended for use in wetlands.

Small Boat Harbors

1. Small boat harbors should only be located on bodies of water with a high rate of flushing.

2. Small boat harbors should be designed to minimize the extent of excavation, shoreline alteration, and disturbance of vital habitat areas.

3. In order to eliminate channel excavation, floating docks should be used whenever possible. When it is not appropriate to use floating docks, piers built on pilings should be constructed over wetlands to provide access to deep waters. The piers should connect to land above the annual flood level.

4. The natural coastline should be preserved by placing boat slips farther out into the water and connecting them to the shore with piers. This will eliminate the adverse impacts of dredging and bulkheading.

5. Small boat harbors should not be constructed in wetlands. Piers and docks can be designed to extend over the wetlands to deep waters on pilings.

6. The construction of bulkheads, groins, and jetties should be avoided when building small boat harbors.

7. Support facilities for small boat harbors, including storage areas and buildings, should be located inland away from the coastline.

Coastal Pipelines

(See additional recommendations for pipelines in the Oil Pollution section)

1. Pipelines should not be placed in vital habitat areas such as wetlands, eelgrass beds, or clam beds.

2. When habitat disturbance is unavoidable, construction activities should be limited to the shortest time and smallest area possible.

3. Pipelines should be built during periods of low biological productivity (see Table 31).

4. After the pipeline is laid, the construction area should be restored to as close to its original state as possible, using original substrate and native species wherever feasible.

Coastal Roads

1. Build roads perpendicular rather than parallel to the coast.

2. Coastal roads should not cross wetlands.

3. Stream crossing should be designed to allow fish passage during any flow. Bridges are preferred. If culverts must be used, the following guidelines should be followed:

   a. Culverts placed in rivers or streams frequented by fish should be installed so that at least one-fifth of the diameter of round culverts or six inches of elliptical or arch culverts is set below the lowest elevation of the natural stream bottom.

   b. Culvert dimensions necessary to pass fish upstream are dependent upon the velocity of the water within the culvert when the fish are present; the time of year these velocities occur; the length of the culvert which must be negotiated by the fish; and the species, size, and age class of fish present and their upstream swimming capabilities. Table 30 represents the maximum water velocities through different culvert lengths which can be successfully negotiated by several Alaskan fish species. To avoid the possibility of restricting fish passage, velocities through culverts should not exceed 0.5 fps.

TABLE 30

Maximum water velocities through different culvert lengths which can be successfully negotiated by several Alaskan fish species.

Length of culvert in feet	Group I Upstream migrant salmon fry and fingerlings when upstream migration takes place at mean annual flood	Group II Adult spring spawning slow swimmers: grayling longnose suckers	Group III Adult moderate swimmers: pink salmon chum salmon	Group IV Adult high performance swimmers: king salmon coho salmon sockeye salmon steelhead.	Group V Juvenile slow swimmers and other adult slow swimmers: grayling, longnose suckers, broad whitefish, burbot, sheefish, humpback whitefish, Northern pike, Dolly Varden/ Arctic Char, upstream migrant salmon fry and fingerlings when migration not at mean annual flood
30	1.0	3.7	6.8	9.9	2.0
40	1.0	3.1	5.8	8.5	1.8
50	1.0	2.6	5.0	7.5	1.7
60	0.9	2.3	4.6	6.6	1.6
70	0.8	2.1	4.2	6.0	1.4
80	0.8	1.9	3.9	5.5	1.3
90	0.7	1.7	3.7	5.1	1.2
100	0.7	1.6	3.4	4.8	1.2
150	0.5	1.5	2.8	3.7	1.2
200	0.5	1.5	2.4	3.1	1.2
>200	0.5	1.5	2.4	3.0	1.2

feet/second

Source: Alaska Boards of Fisheries and Game and Alaska Department of Fish and Game Proposed Regulations Governing Fish and Game Habitat Protection

c. Alternative drainage structures, other than culverts, should be installed if fish passage cannot be assured through culverts.

d. All culverts should be aligned with the natural stream channels.

e. All bank cuts, slopes, fills, and exposed earth work attributable to culvert installation should be stabilized to prevent erosion during and after the project.

f. No culverts should be built in fish spawning or rearing areas. Roads crossing streams at such critical habitats should be re-routed or a bridge installed instead of a culvert.

In order to implement these guidelines, site specific studies will have to be conducted on a case-by-case basis. In instances where information is not available regarding the effects of shoreline alteration on various stages of animal life history, more research will have to be done to determine these impacts.

HIGH SENSITIVITY AREAS

The designation of high sensitivity was given to areas where impacts from shoreline alteration are likely to be extremely adverse to fish, wildlife, and aquatic plants. These highly sensitive habitats include:

1. Areas of first open water in spring
2. Eelgrass beds and lagoons
3. Highly productive/heavily used wetlands and tideflats and wetlands and tideflats when productivity is not known
4. Herring spawning areas
5. Mouths of salmon streams
6. Seabird concentration areas on water at base of colonies and waterfowl and shorebird spring concentration areas
7. Marine mammal haulouts including recurrent and occasional walrus haulouts, spotted seal haulouts, and sea lion haulouts.

Structures which cause shoreline alteration should not be sited in areas of high sensitivity.

TABLE 31 : MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND SPECIES, HABITATS OR HARVEST ACTIVITIES ARE MOST SENSITIVE TO SHORELINE ALTERATION.

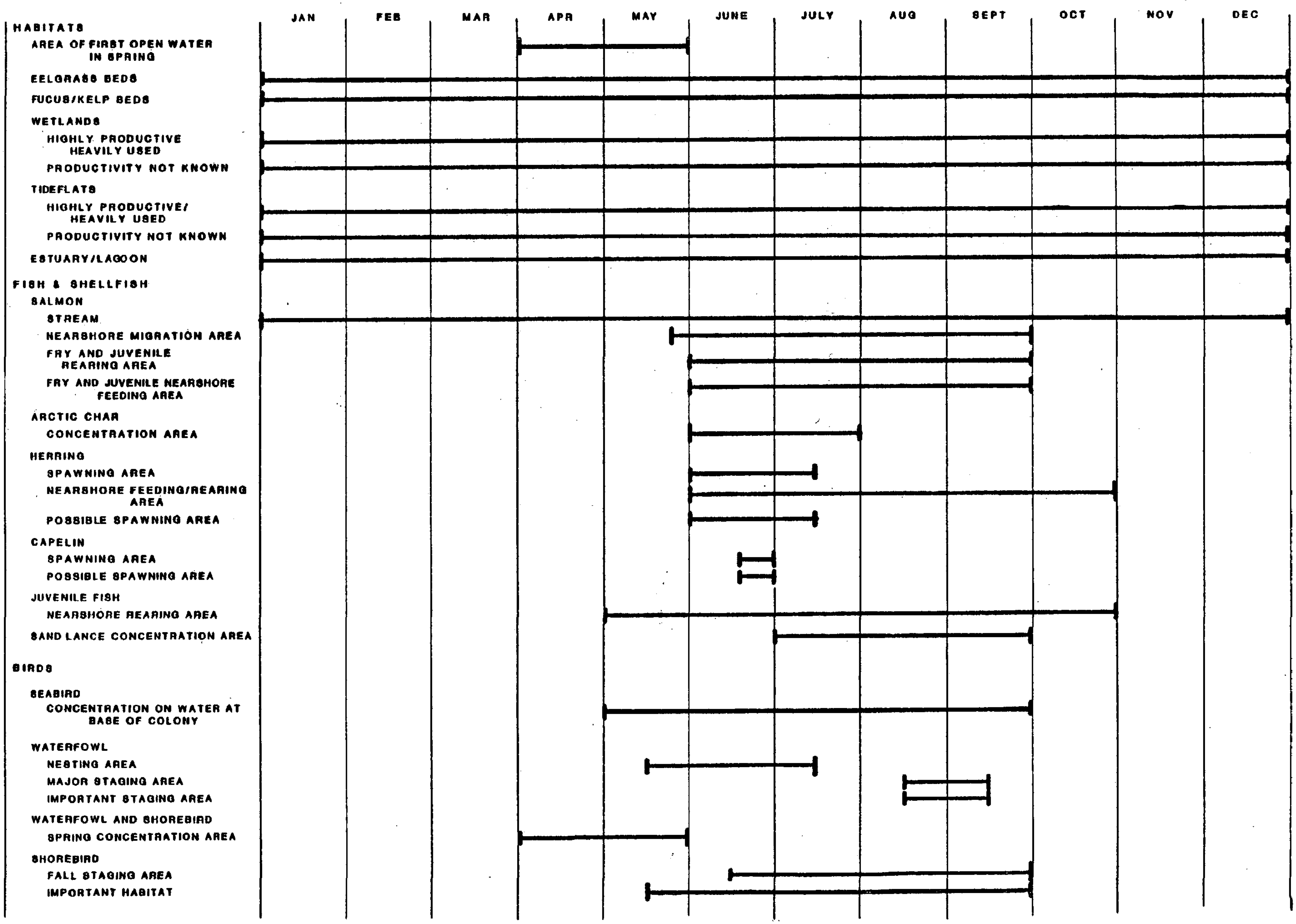
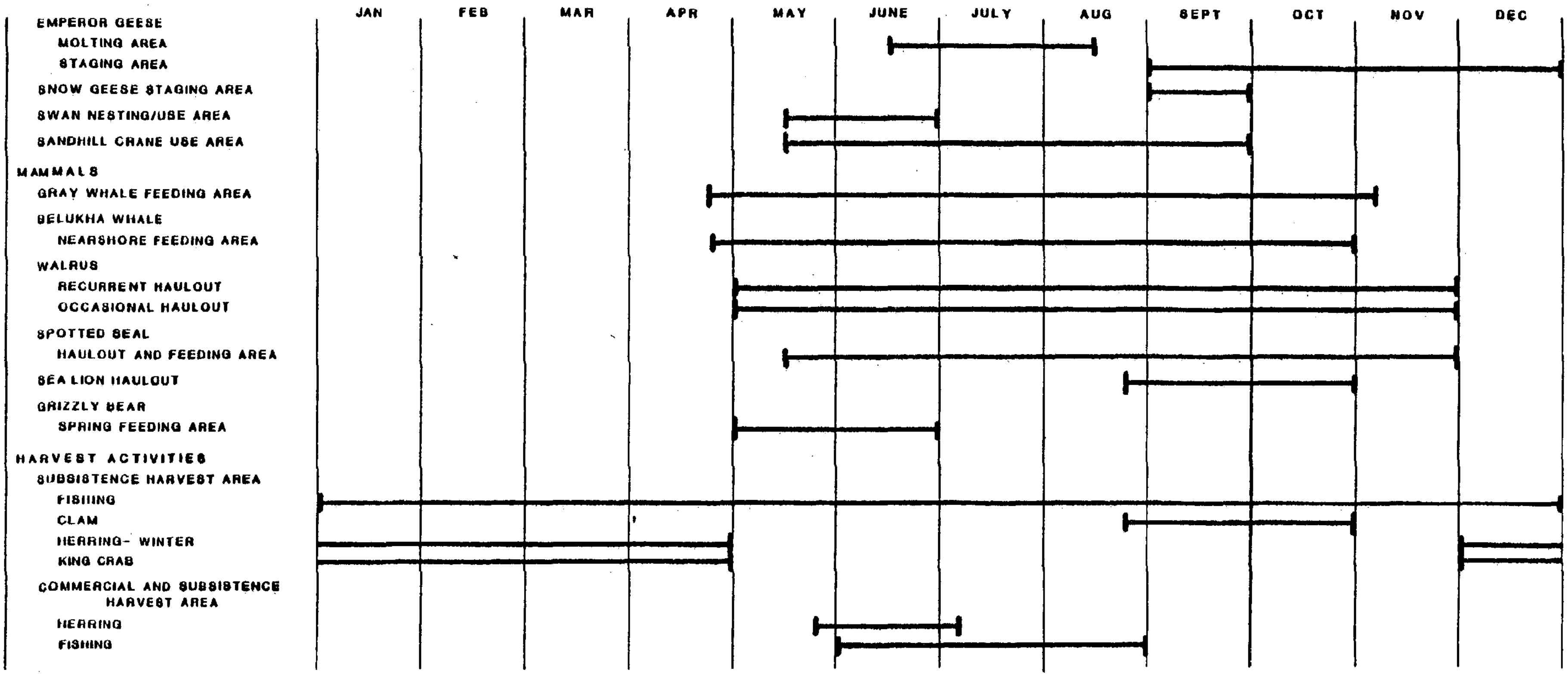


TABLE 31: (CONT.) MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND SPECIES, HABITATS OR HARVEST ACTIVITIES ARE MOST SENSITIVE TO SHORELINE ALTERATION.



G

FORMATION WATERS

FORMATION WATERS

Sources and Biological Effects

The discharge of formation waters from offshore drilling platforms or onshore treatment facilities may adversely impact aquatic organisms. Crude oil as it comes from the ground is generally made up of natural gas, petroleum, and water. The water, called formation or produced water, is contaminated with hydrocarbons and may be contaminated with heavy metals and hydrogen sulfide, all of which may pollute marine and freshwater environments (Longley et al., 1978)(see Tables 32-35). Before the crude oil is delivered to a refinery, the water must be separated from the oil and gas. This process can take place on the offshore production platform, or, if the crude oil is transported ashore by pipeline the oil, water, and gas will be separated at onshore treatment facilities. Once the formation water is separated from the oil and gas, it is generally treated by heat or chemicals and discharged back into marine waters, sometimes in the same location for 20-30 years (Longley et al., 1978; Mackin, 1973). Formation waters may also be injected into disposal wells or pumped back into reinjection wells to maintain pressure (USDI, 1976). The amount of production water is usually small during the initial life of an oil field, but increases progressively as the field is depleted and water invades the rock formation of the natural reservoir (Read and Blackman, 1980). Production statistics compiled for individual wells and oil fields throughout Alaska show a wide variability with respect to oil and water recovery rates. During 1980, the Trading

Table 32
Range of Constituents in Produced
Formation Water
--Offshore California 1/

Effluent Constituent	Range, mg/l	State of California 2/ Ocean Effluent Limits mg/l
Arsenic	0.001 - 0.08	0.02
Cadmium	0.02 - 0.18	0.03
Total Chromium	0.02 - 0.04	0.01
Copper	0.05 - 0.116	0.3
Lead	0.0 - 0.28	0.2
Mercury	0.0005 - 0.002	0.002
Nickel	0.100 - 0.29	0.2
Silver	0.03	0.04
Zinc	0.05 - 3.2	0.5
Cyanide	0.0 - 0.004	0.2
Phenolic Compounds	0.35 - 2.10	1.0
BOD 5	370 -1,920	
Chlorides	17,230 - 21,000	
TDS	21,700 - 40,400	
Suspended Solids		
Effluent	1 - 60	
Influent	30 - 75	
Oil and Grease	56 - 359	

1/ Some data reflect treated waters for reinjection.
2/ Concentrations not to be exceeded more than 10% of time.

Source: Environmental Protection Agency, 1974.

Table 33
Range of Constituents in Produced Formation Water --Offshore Texas

Effluent Constituent	Range, mg/l
Arsenic	<0.01 - <0.02
Cadmium	<0.02 - 0.193
Total Chromiun	<0.10 - 0.23
Copper	<0.10 - 0.38
Lead	<0.01 - 0.22
Mercury	<0.001 - 0.13
Nickel	<0.10 - 0.44
Silver	<0.01 - 0.10
Zinc	0.10 - 0.27
Cyanide	N. A.
Phenolic Compounds	53
BOD 3	126 - 342
COD	182 - 582
Chlorides	42,000 - 62,000
TDS	806 - 169,000
Suspended Solids	12 - 656

N.A. - not available

Source: Environmental Protection Agency, 1974.

Table 34
Averages of Constituents in
Produced Formation Water
--Gulf of Mexico

Influent	
Oil and Grease	202 mg/l
Effluent	
Cadmium	0.0678 mg/l
Cyanide	0.01 mg/l
Chlorides	61,142 mg/l
Mercury	Trace
Total Organic Carbon	413 mg/l
Salinity	110,391 mg/l
API Gravity	33.6 degrees
Suspended Solids	73 mg/l

Volumes

Range - 250 to 200,000 bbls brine water/day

Average - 15,000 bbls brine water/day

Source: Environmental Protection Agency, 1974

Table 35
Typical Characteristics of
Effluent from Water Treatment Facilities

Phillips Petroleum Company
Lease OCS-P 0166 - La Conchita Plant

Physical Properties		Chemical Properties mg/l	
pH	7.3	Aluminum	2.2
Specific Gravity	1.02	Ammonia, N	39.7
Turbidity	12 JTU	Arsenic	0.001
Total Dissolved Solids (Calc.)	40,400 mg/l	Barium	0.
Total Solids	20,990 mg/l	Bromide	183.8
Total Volatile Solids	1,810 mg/l	Cadmium	0.030
Total Suspended Solids	56 mg/l	Chromium	0.020
Settleable Solids	0.1 mg/l	Copper	0.116
Floatable Solids	0.3 mg/l	Cyanide	0.004
Temperature	77°F	Fluoride	1.7
		Iron	1.35
		Lead	0.28
Specific Conductance	31,630 m-mhos/cm		
Max. $CaSO_4$ Possible (Calc.)	0. mg/l	Magnesium	50.0
Max. $BaSO_4$ Possible (Calc.)	0. mg/l	Manganese	0.062
Alkalinity as $CaCO_3$	3,480 mg/l	Mercury	0.0005
		Nickel	0.29
Dissolved Solids		Nitrate, N	0.0
Cations		Nitrate, Ni	0.000
Total Hardness	10 me/l	Kjeldahl Nitrogene	54.6
Sodium, Na^+(Calc.)	15,000 mg/l	Phosphorus-Ortho, P	1.54
Calcium, Ca^{++}	80 mg/l	Phosphorus, P	1.89
Magnesium, Mg^{++}	72 mg/l	Silver	0.030
Iron (Total), Fe^{+++}	1.0 mg/l	Zinc	0.18
Anions		Phenolic Compounds C_6H_5OH	2.10
Chloride, Cl^-	21,000 mg/l	Identifiable Chlorinated Hydrocarbons	None
Sulfate, $SO_4^=$	0. mg/l		
Carbonate, $CO_3^=$	0. mg/l	Radioactivity	
Bicarbonate, HCO_3^-	4,270 mg/l	Gross Alpha Activity	None Detected
Hydroxyl, OH^-	0. mg/l	Gross Beta Activity	None Detected
Sulfide, $S^=$	1.1 mg/l	Oil and Grease	5.0
Dissolved Gases			
H_2S	0.4 mg/l		
CO_2	320 mg/l		
O_2	0.3 mg/l		

Source: USGS Santa Barbara EIS, pp. II-616
NERBC, 1976

Bay oil field in Cook Inlet produced roughly 2.2 million barrels of oil in conjunction with 6 million barrels of water. The cumulative oil-to-water ratio for the Trading Bay field since its inception in 1967 is approximately 81 million barrels of oil to 43 million barrels of water. In Prudhoe Bay, statistics for 1980 show approximately 555 million barrels of oil were recovered with only 13 million barrels of associated water. The cumulative oil-to-water ratio for the Prudhoe field is approximately 1.5 billion barrels of oil to 23 million barrels of water (AOGCC, 1981).

The amount, and therefore the effect, of discharged formation water on biological communities in receiving waters is determined by the size of a treatment facility and the ability of receiving waters to accommodate such wastes. Because onshore treatment facilities may collect oil from several offshore platforms, the amount of formation water discharged will be considerably greater than that which is discharged from treatment facilities on individual platforms. It may also be assumed that the biological effects from a single onshore treatment facility discharging formation waters into shallow nearshore waters will be significantly greater than the collective effects of formation waters discharged from several deep water offshore platforms.

Formation waters may be highly toxic and their disposal into the marine environment can be detrimental (NERBC, 1976). Formation waters may contain up to 50 ppm of oil as small droplets and up to 35 ppm of dissolved hydrocarbons, primarily aromatic fractions (Koons et al., 1977).

Levels of total dissolved aromatic hydrocarbons below 1 ppm have been found to be acutely toxic to larval crustaceans (Anderson, 1977; Mecklenburg et al., 1976). Formation water may also contain toxic quantities of heavy metals, such as vanadium and mercury, and hydrogen sulfide, a poisonous gas. All formation waters are anoxic, and the concentrations of dissolved salts may vary greatly from those of receiving waters.

Polluted formation waters may affect both individual organisms and entire populations by causing short term (acute or lethal) biological effects such as death, or long term (chronic or sublethal) effects including abandonment of habitat and interference with growth and reproduction. Formation waters appear to be more harmful if they are discharged into shallow waters rather than deeper waters because larger bodies of water which support tidal action, waves, and strong currents will tend to rapidly dilute the toxic components. Because of their ability to avoid contaminated waters, fish and free swimming organisms do not seem to be greatly affected by formation water discharge. The effects on free floating plankton seem to be similar and localized. However, in shallow waters where dilution by seawater may not take place, benthic (bottom dwelling) organisms living near the point of discharge may be totally destroyed (Armstrong et al., 1979). The oil in formation waters can adhere to sediment particles in the water column and settle to the bottom causing contamination of the bottom substrate. When accumulations reach a sufficient level, destruction of bottom communities occur (Mackin, 1973). This information suggests that although the concentration of oil in water may be low, oil may be accumulating in bottom sediments over a long period of time. In order to avoid impacting bottom communities, these sediments should be carefully monitored.

The effects of formation waters seem to decline further from the point of discharge because of dilution by marine waters (Mackin, 1973). Mackin (1971) studied the effect of produced waters on marine plankton, benthic, and pelagic communities of six oil fields located in Texas estuaries. Bottom communities within 15 meters (50 feet) of heavy discharges were almost completely destroyed, whereas organisms from 45 to 61 meters (150 to 200 feet) appeared to receive noticeable, but less impact. At 91 meters (300 feet) no short term impact was observed (Mackin, 1973).

A more recent study by Armstrong, et al. (1979) showed that although receiving water concentrations of aromatic hydrocarbons some distance from oil platforms were very low, the concentrations of several alkyl-substituted naphthalene compounds in the sediments were four orders of magnitude higher than in the overlying water. It was further believed that persistant concentrations of naphthalenes as low as 2 ppm in sediment were capable of excluding benthic organisms from an area. In the study, benthic communities were reported to be "severely depressed" within an area extending 150 meters (492 feet) outward from any platform discharging formation waters. This suggests that by looking strictly at water column concentrations the major sink of hydrocarbons may be missed.

In a study by Mackin and Hopkins (1962) in Louisiana, trays of oysters placed within 7.6 meters (25 feet) of a formation water discharge site suffered very heavy mortalities near the bottom of the water column and slightly less at the top. Some mortality was observed out to 23 meters (75 feet), and between 23 and 46 meters (75 to 150 feet) there was evidence of stunted growth. Beyond 46 meters (150 feet) the report did not identify any further evidence of adverse effects.

As previously mentioned, formation waters are often contaminated with hydrocarbons, sulphurous wastes, and heavy metals (Levorsen, 1967). Organisms react in various ways to these different contaminants. Soluble hydrocarbons, heavy metals and hydrogen sulfide, even at low concentrations, are known to be toxic to marine life (Shaw, 1976). As a result, there may be a short, catastrophic impact or a more subtle long term interference with growth and reproduction. Non-hydrocarbon constituents of formation waters cause various adverse effects on fish and other aquatic organisms. For example, ammonia, a constituent of formation water, produces gill enlargement (hyperplasia) in fingerling chinook (king) salmon. Mercury, another heavy metal found in formation waters has been shown to concentrate in fish in excess of 10,000 times the amount present in surrounding water. The heavy metal lead, in concentrations of 0.3 ug/l, impaired the reproduction of zooplankton, particularly, Daphnia major (NERBC, 1976).

Other metallic components in formation waters have also been found to affect marine life. Portman (1972) found that shrimp exhibited a positive avoidance reaction to copper in concentrations as low as 0.33 ppm. However, no avoidance reaction was observed with shrimp exposed to mercury (up to 100 ppm) or zinc (up to 33 ppm); on the contrary, there appeared to be an attraction effect at lower concentrations. Since the 48 hour LC50 for mercury was reported to be between 3.3 and 10 ppm, an attraction effect at concentrations just below this figure could have serious consequences, particularly if the more susceptible larvae exhibit the same behavior.

Formation waters are not only contaminated with toxic chemicals and gases but are anoxic (depleted of oxygen) as well, and may have higher temperatures and/or lower salinity values than receiving waters (Levorsen, 1967). Waters depleted of oxygen can kill animals directly, although the usual effect is impairment of health or, if they are mobile, abandonment of the area. For example, striped bass spawning was eliminated in the Delaware River near Philadelphia because depleted oxygen levels deterred the fish from migrating upstream to their spawning grounds. Salinity (the amount of salt dissolved in water) is important to the marine environment because it affects the type and distribution of organisms living in an aquatic environment. Because some species are broadly tolerant and others are narrowly tolerant of salinity changes, there may be interference with their survival, spawning or reproduction, optimum growth conditions, and daily or seasonal movements during various life history stages (Clark, 1977). Discharges of high salinity waters into freshwater lakes or streams, or low salinity waters into highly productive marine environments such as clam beds could be very destructive.

The biological effects of low level hydrocarbon exposure are discussed in the section on Oil Pollution.

Table 36 Effects of formation waters and formation water components on fish, wildlife, aquatic plants and their habitats

Species/Habitat	Reference	Type of Experiment	Product	Concentration	Effect and Evaluation
SALMONIDS					
Acute/Toxic Effects					
Steelhead (*Salmo gairdneri*) Coho Salmon (*Onchorynchus kisutch*)	Chapman & Stevens, 1978	acute toxicity, bioassay	heavy metals (cadmium, zinc and copper)	5.2 to 1,755 ug/l	The 96 hr LC50 values for adult male coho salmon and steelhead respectively were 46 and 57 ug/l for copper, and 905 and 1,755 ug/l for zinc. Mortality induced by cadmium was slow in onset but 50% mortality occurred after more than a week at 3.7 ug/l for coho salmon and 5.2 ug/l for steelhead. Water hardness and alkalinity affected the toxicity levels.
Juvenile King Salmon (*Oncorhynchus tshawytscha*) Steelhead Trout (*Salmo gairdneri*)	Chapman, 1978	continuous flow toxicity tests	heavy metals (cadmium, zinc and copper)	ppm	The 96 hr LC50 values for four juvenile life stages of king salmon and steelhead ranged from 1.0 to > 27 ug Cd/l, 17 to 38 ug Cu/l and 93 to 815 ug Zn/l. The 200 hr LC50 ranged from 0.7 to > 27 ug Cd/l, 7 to 30 ug Cu/l and 54 to 555 ug Zn/l. Newly hatched alevins of both species were more resistant to cadmium and zinc. Later juvenile stages were most sensitive. Copper sensitivities showed little relationship to life history stages. Steelhead were consistently more sensitive to these metals than were king salmon.
Rainbow Trout (*Salmo gairdneri*) Chinook Salmon (*Oncorhynchus nerka*)	Rucker and Amend, 1969	histopathological examination	heavy metals (mercury)	ppm	Results indicate that mercury accumulation is greatest in the liver and kidneys of fish exposed to soluble mercury compounds or which consume mercury contaminated prey. Highest levels of accumulation were recorded at 39.6 ppm in kidney tissues of 8-inch rainbow trout exposed to 12 weekly one-hour exposures of 2 ppm Timson (6.25 percent ethyl mercury phosphate). Thirty-three weeks after exposures were discontinued 12.3 ppm mercury was still present in kidney tissue. Two year old chinook salmon were also fed fingerlings contaminated with 3 ppm mercury. Accumulations reached a high level of 30.5 ppm in liver tissues, indicating that significant contamination and bioaccumulation may occur through predation.
Salmon (*Oncorhynchus* sp.)	McKee & Wolf, 1963	literature review	hydrogen sulfide H_2S	0.3 to 1.0 mg/l	0.3 and 0.7 mg H_2S/l were survived by king salmon and silver salmon respectively, while 1.0 and 1.2 mg H_2S/l were toxic.
Coho Salmon (*Oncorhynchus kisutch*)	Chapman, unpublished	bioassay	heavy metals (lead)	6.8 mg/l	50% of four week old coho salmon were killed by a four day exposure to lead concentrations of 0.8 mg/l.
Coho Salmon (*Oncorhynchus kisutch*)	Katz and Pierro, 1967	toxicity effects	ammonia		Toxicity of ammonia to coho salmon increases with increasing salinity.

ppt = parts per thousand
ppm = parts per million
ppb = parts per billion

LC50 = concentration required to kill 50% of the test animals
TLM = median tolerance limit - the concentration required to kill 50% of the test animals within certain time limits

Species/Habitat	Reference	Type of Experiment	Product	Concentration	Effect and Evaluation
Juvenile Atlantic Salmon (Salmo salar)	Herbert & Shurben, 1965	toxicity effects	ammonia	0.2 mg/l	Concentrations of ammonia greater than 0.2 mg/l are toxic to Atlantic salmon smolts.
Rainbow Trout (Salmo gairdneri)	Brown, 1968	bioassay	heavy metals (lead)	1 mg/l	96 hr LC50 for rainbow trout was 1 mg Pb/l.
Brook Trout (Salvelinus frontinalis)	Benoit et al., 1976	bioassay	heavy metals (cadmium)	.06 ug/l	Exposure to 3.4 ug/l Cd resulted in the death of a significant number of first and second generation brown trout males during spawning. This concentration also significantly retarded growth of juvenile second and third generation offspring. Bioaccumulation of cadmium occurred in gill, liver, and kidney tissue and was directly related to exposure concentrations. Depuration was rapid from gills but no loss was detectable from liver or kidney tissue.
Juvenile Rainbow Trout (Salmo gairdneri)	Wobeser, 1973	bioassay	heavy metals (mercury)	24-42 ug/l	50% of newly hatched fry and fingerling rainbow trout were killed by mercury concentrations of 24 and 42 ug/l.
Rainbow Trout (Salmo gairdneri)	Wobeser, 1975	bioassay	heavy metals (mercury)	4, 8, 16, and 24 ppm methyl mercury chloride	No mortalities occurred as a result of these experiments. The accumulation of mercury in tissues was directly related to the concentration of mercury in food, with those fish receiving a higher concentration accumulating mercury at a more rapid rate. Individual fish in all groups had higher mercury concentrations in their muscle than were present in their diet.
Physiological Effects					
Juvenile Coho Salmon (Oncorhynchus kisutch)	Burrows, 1964	toxicity effects	ammonia	0.002 mg/l	Progressive gill hyperplasia is produced in fingerling chinook salmon at concentrations of 0.002 mg/l of ammonia.
OTHER FISH					
Acute/Toxic Effects					
Channel Catfish (Ictalurus punctatus)	Bonn & Follis, 1967	bioassay	hydrogen sulfide H_2S	1.5 to 10.9 ppm undissolved sulfides (0.4 to 0.9 ppm unionized H_2S)	3 hr TLM's exposed to un-ionized hydrogen sulfide for channel catfish fry ranged from 0.8 ppm at a pH of 6.8 to 0.53 ppm at a pH of 7.8. Most deaths occurred within 10 minutes at the TLM values. Fingerling catfish were more sensitive than adults.
Fathead Minnow (Pimepheles promelas)	Pickering & Henderson, 1966	bioassay	heavy metals (lead)	5.6 to 7.3 mg/l	96 hr LC50 for fathead minnows was 5.6 to 7.3 mg Pb/l.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Physiological Effects					
Flagfish (*Tordanella floridae*)	Spehar et al., 1978	toxicity effects	heavy metals (zinc and cadmium)	4.3 to 8.5 ug Cd/l 73.4-139 ug Zn/l	A comparison of survival rates of flagfish exposed to cadmium and zinc as individual metals and as mixtures showed that the toxicity of the mixtures was little if any greater than the toxicity of zinc alone. Cadmium and zinc did not act additively when combined at sublethal concentrations, however, joint action was indicated. Tissue uptake of one metal was not influenced by the presence of the other metal. A significant decrease was observed in the survival of larvae exposed as embryos to individual zinc and cadmium concentrations. However, similar effects on survival were not observed with progeny of earlier chronic tests.
Winter Flounder (*Pseudopleuronectes americanus*)	Schmidt-Nielsen 1977	intramuscular injection-histopathological examination	heavy metals (mercury)	4mg CH_3HgCl/ml in 50% ethanol solution	Increase in mercury concentration in tissues was roughly proportional to the total dose given. Accumulation of mercury in gills up to 24 ppm did not decrease the ability of the flounders to hypo-osmoregulate as has been reported for other fish species (Renfro et al., 1974).
Bluegill (*Lepomis macrochirus*)	Atchison et al., 1977	observation of contaminated lakes	heavy metals (zinc, lead, cadmium)	1.1 to 270 ug/l suspended in water and 4.4 to 12,800 ug/g dry weight in sediment	The relative levels of contamination in bluegills from two metal contaminated lakes closely resembled the relative concentrations of metals in the water and sediment at each site. Up to 3.4 ug Cd/g dry weight of tissue, 220 ug Zn/g dry weight tissues and 6.1 ug Pb/g dry weight tissue were found in bluegills from the contaminated lakes. These levels were significantly above levels found in fish from uncontaminated lakes.
Fathead Minnows (*Pimepheles promelas*)	Mount, 1974	toxicity effects	heavy metals (mercury)	0.07 to 0.12 ug/l	Fathead minnows did not spawn and males did not develop sexually when exposed to mercury concentrations of 0.12 ug/l. No toxic effects were noted at 0.07 ug/l.
Fathead Minnows (*Pimepheles promelas*)	Pickering, 1974	bioassay-toxicity effects	heavy metals	380 ug/l	Survival, growth and reproduction of fathead minnows were unaffected at and below nickel concentrations of 380 ug/l.
Fish	McKim, 1974	toxicity effects	heavy metals (mercury)		Concentrations of mercury in excess of 10,000 times those present in surrounding water have been found in fish.
Behavioral Effects					
Channel Catfish (*Ictalurus punctatus*)	Bonn & Follis, 1967	bioassay	hydrogen sulfide H_2S	sublethal	When catfish of varying ages were exposed to sublethal concentrations of unionized hydrogen sulfide (0.2 ppm of TLM for given pH) they exhibited nervousness and hyperactivity.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
SHRIMP					
Acute/Toxic Effects					
Shrimp (Penaeus duorarum and Palaemonetes vulgaris)	Nimmo et al., 1977	flow through bioassay and toxicity tests	heavy metals (cadmium)	.079 mg/l to 1.285 mg/l	The 96 hr and 30 day LC50's for pink shrimp (P. duorarum) were 3.5 mg Cd/l and 0.718 m Cd/l respectively. The 96 hr and 29 day LC50's for grass shrimp (P. vulgaris) were 0.76 mg Cd/l and 0.12 mg Cd/l respectively. Shrimp bioaccumulated cadmium up to 57 times surrounding water concentrations. Bioaccumulation occurred at concentrations as low as 2 ug/l. Exposure of shrimp to cadmium concentrations close to LC50's resulted in blackened gills, which were sloughed off by surviving shrimp after return to clean water. Cadmium was also accumulated from contaminated food but at a much lower rate.
European Brown Shrimp (Crangon crangon) European Cockle (Cardium edule)	Portmann, 1972	bioassay	heavy metals	ppm	Toxicity data for heavy metal ions are as follows:

Metal ion tested	Valency	48 h LC50 in ppm, w/v: Crangon crangon	Cardium edule	Fish*	
Copper	2+	10-33	1	1-3.3	(F)
Chromium	6+	100	100-330	33-100	(A)
Iron	3+	33-100	100-330		
Mercury	2+	3.3-10	3.3-10	3.3	(F)
Nickel	2+	100-330	>330		
Zinc	2+	100-330	100-330		

* (A) = Agonus cataphractus; (F) = Pleuronectes flesus (Portmann, 1972)

Behavioral effects were tested by observing avoidance reactions to various metal concentrations. Shrimp were found to have a positive avoidance reaction to copper; the minimum concentration causing significant avoidance was between 0.33 and 0.5 ppm, compared with 48 hour LC50 values of 10 to 33 ppm. There was no avoidance reaction to mercury up to 100 ppm or with zinc up to 33 ppm; on the contrary at low concentrations, i.e. with 0.1-1 ppm mercury and 3.3-33 ppm of zinc, there was an attraction effect. Since the 48 hour LC50 for mercury lies between 3.3 and 10 ppm this could have serious consequences, particularly if the more susceptible larvae exhibit the same behavior.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
CLAMS, OYSTERS, MUSSELS					
Acute/Toxic Effects					
Oysters	Oliveira, 1924	toxic effects	hydrogen sulfide H_2S		Hydrogen sulfide generated by a deposit on the bottom of a bay was an important factor in causing the death of young oysters.
Oysters	Menzel & Hopkins, 1951 and 1953	toxicity effects	formation water	discharge of 6000 barrels/day	Trays of oysters within 25 ft of the effluent suffered heavy mortalities. Mortalities were noted out to 75 ft with evidence of stunted growth to about 150 ft. There was evidence of stimulated growth from 150 ft. to about 500 ft.
American Oyster (Crassostrea virginica)	Calabrese et al., 1973	bioassay	heavy metals (nickel)	1.180 m/1	One-half the embryos of American oysters were killed after a two day exposure to nickel concentrations of 1.180 mg/1.
American Oyster (Crassostrea virginica)	Calabrese et al., 1973	bioassay	heavy metals (lead)	1.730 mg/1	One-half of a test population of oyster eggs were killed by a two day exposure to 1.730 mg/1.
Physiological Effects					
American Oyster (Crassostrea virginica)	Pringle, 1968	bioassay	heavy metals (lead)	100-200 ug/1	Long-term exposure to lead concentrations of 100-200 ug/1 causes considerable atrophy and diffusion of the gonadal tissue, edema and less distinction of the hepatopancreas and mantel edge of the American oyster.
Oysters, Diatoms, and Algae	Mackin, 1950	aquaria	formation water	2.5 ppt	Over a 4 month period, heavy growth of algae occurred and the oysters stored significantly more glycogen and had lower mortality than controls.
Behavioral Effects					
Bivalves (Mytilus edulis and Mya arenaria)	Capuzzo and Sasner, 1977	toxicity effects	heavy metals (chromium)	0.01 mg Cr/g clay to 1.2 mg Cr/g clay and 1 mg Cr/1 sea water	Reduction of filtration rates and disturbed ciliary activity were observed in response to uptake of dissolved chromium by Mya arenaria and uptake of dissolved and particulate bound chromium by Mytilus edulis. Inefficient retention of food particles (due to slower erratic movement of the cilia) and a reduction in oxygen consumption were also observed.
Oysters	Lunz, 1950	toxicity effects	Louisiana formation water	10,000-100,000 ppm	A significant decrease in pumping rates of oysters occurred at 100,000 ppm. Pumping returned to normal after oysters were returned to clean water. No changes in pumping rate were noted at 10,000 and 50,000 ppm.

Species/Habitat	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
OTHER AQUATIC SPECIES					
Acute/Toxic Effects					
Copepod (Daphnia magna)	Biesinger & Christensen, 1972	bioassay	heavy metals (nickel)	130 ug/l	A three week exposure to a concentration of 130 ug/l nickel killed one-half the population of Daphnia magna.
Copepod (Arctia tonsa)	Gentile, 1975	bioassay	heavy metals (nickel)	625 ug/l	A four day exposure to nickel concentrations of 625 ug/l killed one-half of the population of the marine copepod, Arctia tonsa.
Benthic Organisms	Armstrong et al., 1979	observation of outflow	formation water	Undiluted effluent 15 ppm total oil, 1.62 ppm total naphthalenes	Sediments 15 m from brine outflow in a shallow bay had hydrocarbon concentrations 4 times as great as concentrations in the effluent, while bottom water 15 m from outfall had 3 orders of magnitude less. The bottom was devoid of organisms within 15 m of outfall and benthic fauna was severely depressed at 150 m. Use of a second temporary outfall resulted in rapid buildup of naphthalenes in the surrounding sediments which persisted for at least 6 months following shutdown. Benthic fauna was also severely depressed near this outfall.
Bottom and Pelagic Communities	Mackin, 1971	toxicity effects	formation water		Studies of formation water discharge in 6 oilfields in Texas estuaries showed bottom communities almost totally destroyed within 50 ft of heavy discharges with a lessening of effect out to 300 ft. A zone of stimulated growth was observed from 400 ft to several thousand feet out.
Fish and Invertebrates	Shaw, 1976	literature review water quality	H_2S & mercaptans (RSH)	1 ppm	Hydrogen sulfide and chemically similar mercaptans (RSH) are poisonous to most fish and most invertebrates at levels up to 1 ppm H2S.
Physiological Effects					
Copepod (Daphnia major)	Biesinger & Christensen, 1972	toxicity effects	heavy metals (lead)	0.3 ug/l	Daphnia major (a small zooplankton organism) showed 16% reproduction impairment when exposed to a lead concentration of 0.3 ug/l.
Copepod (Daphnia magna)	Biesinger & Christensen, 1972	bioassay	heavy metals (nickel)	sublethal	A 16% reproduction impairment was observed in Daphnia magna exposed to nickel concentrations of 30 ug/l.
Copepod. (Daphnia sp.)	Anderson, 1944	toxicity effects	heavy metals (arsenic)	4.3 to 7.5 mg/l	Toxic effects and symptoms of immobility in Daphnia sp. occur at concentrations of 4.3 to 7.5 mg As/l.
Aquatic species (freshwater)	Gilderhaus, 1966	toxicity effects	heavy metals (arsenic)	2.3 mg	Reduced growth of fish, bottom fauna and plankton occurred at concentrations of arsenic at 2.3 mg/l.

Sensitivity of Areas and Recommended Mitigative Measures

Areas in the northern Bering Sea and Norton Sound were ranked as having a low, moderate, or high sensitivity to the impacts of formation water discharge (see Map G). These designations were based on existing data and were made after evaluating the following criteria:

1. The sensitivity of each fish and wildlife species or habitat to the effects of formation water discharge.

2. The degree of sensitivity to formation water discharge as exhibited by each species during the various stages of its life history.

3. The time of year that these critical life history stages occur and the period during which each species would be most affected.

4. The location of habitats where critical life history stages occur.

5. The characteristics of receiving waters.

6. The productivity of the habitat.

7. The uniqueness of the habitat.

8. The species population numbers and relative importance of the population.

9. The degree to which the impacts of formation water discharge could be mitigated.

Specific considerations and assumptions that were made during the course of ranking are as follows:

1. Due to the extreme importance of the nearshore area to a variety of marine species, and because toxic components of formation waters may become concentrated in both organisms (bioconcentration) and substrate (suspended sediment adsorption and settling) if adequate dilution processes do not occur, the very nearshore area seaward to the 30 ft. bathymetric contour line has been designated as a high sensitivity area.

2. The moderate sensitivity designations surrounding St. Lawrence Island, the Yukon Delta, and the mouth of Norton Sound eastward, have been assigned in order to provide a buffer zone against formation water discharge occurring directly adjacent to high sensitivity areas. These designations were applied as a result of weak or unknown circulation regimes, and should act to prevent an accumulation of toxic hydrocarbon fractions within the water column or bottom sediments.

3. Productive habitats such as wetlands, tideflats, estuaries or lagoons have been assigned a high impact value based upon their limited size and demonstrated importance to a variety of

species. Additionally, any formation water discharge in these areas could result in a direct degradation of habitat and a long-term retention of toxic hydrocarbon fractions within reducing sediments.

4. Based on toxicity studies and nearshore rearing requirements, juvenile finfish such as salmon, herring, capelin, and Arctic char are likely to receive the greatest impacts from formation water discharge.

5. Formation waters can be acutely toxic to crustaceans and molluscs, particularly larval forms; however, areas important for critical life history stages in the northern Bering Sea and Norton Sound region are presently unknown, and have not been identified. This should not imply that these areas do not exist or that they are not vulnerable to the toxic effects of formation water discharge.

Sensitivity Designations and Mitigative Measures

LOW SENSITIVITY AREAS

The designation of low sensitivity applies to those areas where the impacts of formation water discharge are believed to be less adverse than in moderate or high sensitivity areas. Such areas would support species or habitats which are relatively resistant to the impacts of formation waters, or which are, for the most part, widely distributed.

Characteristically, low sensitivity areas have strong currents which provide for adequate dilution and dispersion of the toxic components found in formation waters.

Formation waters that are discharged into Federal marine waters must be treated to meet Federal EPA (Environmental Protection Agency) water quality standards. Formation waters that are discharged into State waters (within the 3 mile limit) must meet State water quality standards for petroleum hydrocarbon content, oxygen levels, and toxic substance content, which have been established by the Alaska Department of Environmental Conservation.

MODERATE SENSITIVITY AREAS

The designation of moderate sensitivity applies to areas where the adverse impacts associated with the discharge of formation waters can be prevented, minimized or ameliorated. Species or habitats which are present in these areas are likely to be moderately affected by formation water discharges.

Areas included in this category are:

1. Areas of sluggish circulation
2. Shorefast ice zone
3. Areas receiving longshore sediment transport
4. Eelgrass beds
5. King crab concentration areas

6. Shrimp possible high density areas
7. Clam possible high density areas
8. Herring nearshore feeding and rearing areas
9. Possible herring spawning areas
10. Capelin spawning areas and possible spawning areas
11. Nearshore rearing areas for juvenile fish
12. Bottomfish areas of high abundance, including saffron cod, yellowfin sole, starry flounder, and Arctic cod
13. Salmon nearshore migration areas
14. Sand lance concentrations
15. Seabird concentrations on water at the base of colonies
16. Waterfowl and shorebird spring concentration areas
17. Waterfowl and shorebird nesting, molting, and staging areas, including: major and important waterfowl staging areas, emperor geese molting and staging areas, snow geese staging areas, swan nesting/use areas, sandhill crane use areas, shorebird fall staging areas and important habitat

Formation water discharges should be conducted according to existing environmental regulations. Additional measures to mitigate the impacts of formation water discharges on moderate sensitivity areas include:

1. Wherever possible, formation waters should be reinjected back into offshore or onshore subsurface strata in a manner that will not pollute surface or subsurface waters.

2. Formation waters containing significant amounts (as determined by Environmental Protection Agency or Department of Environmental Conservation marine discharge standards) of heavy metals,

hydrocarbons, hydrogen sulfide, or other toxic chemicals should not be discharged into the marine environment.

3. To insure that all potentially adverse impacts are mitigated, the following information is needed before siting a facility that will discharge formation waters:

   a. A study should be conducted on the body of water into which the formation waters will be discharged in order to determine the rate of flushing; the volume of the water basin; the pattern of water movement; and the suspended sediment load by season.

   b. The type of facility that will be discharging formation water, the rate, volume, and composition of formation water that will be discharged; and

   c. The degree to which formation waters will have to be treated before being discharged so that they do not alter or reduce the carrying capacity of the coastal environment.

In order to implement these guidelines, site specific studies will have to be conducted and mitigating measures adopted on a case by case basis. In many instances, the chemical composition and quantity of formation water will need to be monitored prior to setting effluent limitations. In instances where information is not available regarding the effects of formation waters on the various stages of animal life history, more research will have to be done to determine those impacts.

4. Do not discharge formation waters into any freshwater lake or stream.

5. Facilities should not be located in vital habitats such as wetlands, tideflats or estuaries. These highly productive areas are important for the production and harvest of waterfowl, crabs, clams, herring, salmon, and a variety of other fish species.

6. Facilities releasing formation waters should be sited in areas with good circulation and strong currents, where the discharged effluent will be rapidly diluted and dispersed. Formation water discharge into shallow waters with weak circulation will cause the greatest environmental damage and is discouraged.

HIGH SENSITIVITY AREAS

Areas of high sensitivity are defined as those habitats where the impacts of formation water discharge are likely to be extremely adverse to fish and wildlife resources. The nearshore area seaward to the 30 ft. bathymetric contour line would be included in this designation.

High sensitivity areas include:

1. Recurrent spring open water areas
2. Wetlands, tideflats, estuaries or lagoons
3. *Fucus* kelp beds and eelgrass concentrations
4. Arctic char concentrations
5. Herring spawning and wintering areas
6. Juvenile fish nearshore rearing areas
7. Salmon steams
8. Salmon fry nearshore feeding and rearing areas
9. Sheefish/whitefish streams

Facilities that are designed to discharge formation waters into surface waters should not be sited in areas of high sensitivity because of the potential adverse effects of acute or chronic oil and heavy metal pollution. Reinjection or disposal wells are an environmentally suitable alternative to surface discharge in these sensitive habitats if subsurface aquifers and permafrost are protected.

TABLE 37: MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND SPECIES OR HABITATS ARE MOST SENSITIVE TO FORMATION WATERS

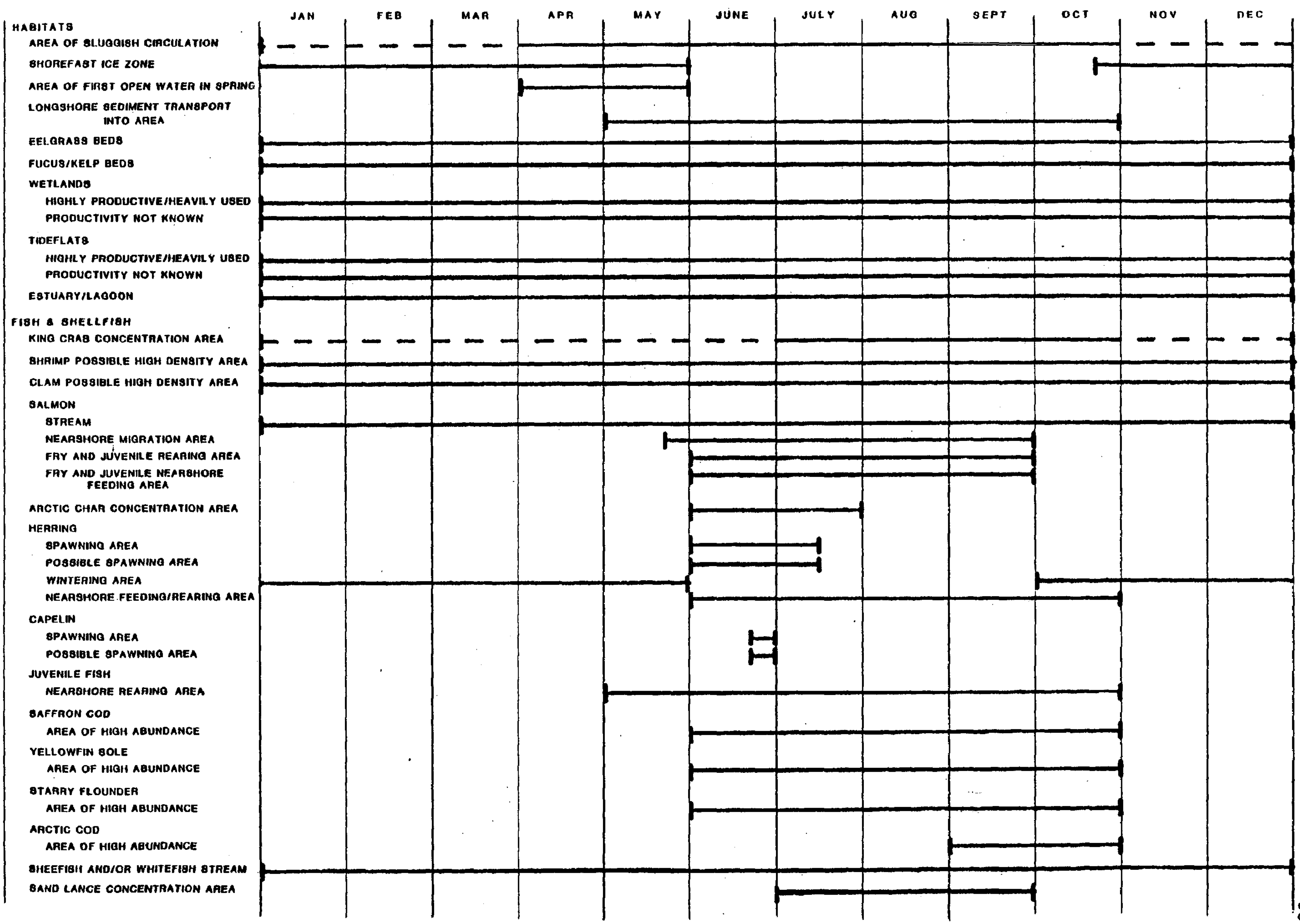
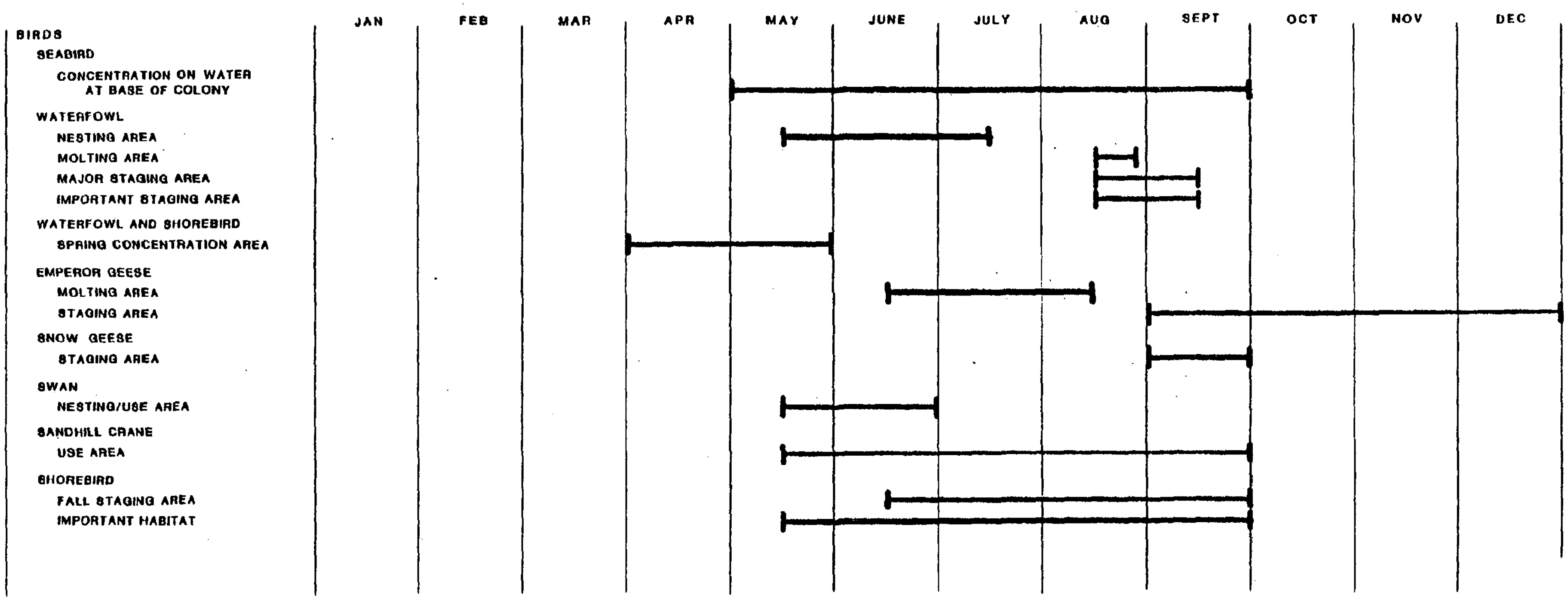


TABLE 37 : (CONT.) MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND SPECIES OR HABITATS ARE MOST SENSITIVE TO FORMATION WATERS



H

COOLING WATERS & WATER WITHDRAWAL

COOLING WATERS AND WATER WITHDRAWAL

Sources and Biological Effects

Various oil and gas related facilities including treatment facilities, oil refineries, petrochemical plants, LNG (liquified natural gas) plants, and power plants (providing energy for oil and gas facilities) require large quantities of water for cooling and processing purposes (Longley et al., 1978; DCRA, 1978). Water is also required for drilling, construction and maintenance of snow and ice roads, dust control, hydrostatic testing, waterflooding (the injection of water into the formation to increase pressure at the well site), and for domestic use. Water requirements are met by drawing water from nearby lakes, streams, springs, estuaries, lagoons, bays, or the ocean, by collecting groundwater runoff, or by melting snow and ice.

Cooling Waters

Cooling waters are used to reduce waste heat produced by the various industrial processes associated with production and processing of oil and gas products. Both open cycle and closed cycle cooling systems are used to cool industrial waste water. Open cycle cooling systems use natural water bodies as both a source of cooling water and a means of disposing of the heated effluent; whereas, closed cycle cooling systems recirculate water within the cooling structure. Closed cycle systems may utilize air cooling towers, cooling ponds, or spray canals. Closed cycle cooling systems have been designed so that they use only 2 to 4% as much water as is used by open cycle cooling systems. Consequently, only 1/25 to 1/50 of the aquatic organisms that are destroyed by once-through cooling systems are destroyed by using closed cooling systems. Currently, most facilities that use large quantities of cooling waters are designed to operate with closed cooling systems. Open cycle systems have become less environmentally desirable because of their potential damage to aquatic systems, the increasing size of the industrial plants, and the limited supplies of cooling water available. Closed cycle cooling systems are more expensive to build and operate, but cause less damage to the aquatic environment (Clark, 1977).

Any oil and gas related facility with an open cycle cooling system, which withdraws large quantities of water for cooling and then discharges the heated effluent back into a freshwater or marine environment, will adversely impact fish and wildlife resources. Open cycle cooling is much more destructive than closed cycle cooling, because the cooling waters are extracted from nearby lakes, estuaries, rivers, and underground wells. The aquatic life in these natural waters is threatened by passage through plant cooling systems (entrainment), by entrapment on the protective screens of water-intake structures (impingement), by the discharge of heated water into the aquatic environment (thermal pollution), and by the discharge of toxic chemicals used to prevent fouling by marine organisms (chemical pollution) (Longley et al. 1978; Murarka, 1977).

The use of wells for a cooling water source may also be environmentally damaging because the tremendous amounts of groundwater required may depress the water table, drying up lakes and streams.

Entrainment is the major source of environmental disturbance associated with the use of cooling waters. It is a process by which aquatic organisms such as plankton, fish, and larval stages of shellfish are exposed to heat, shock, turbulence, and abrasion as they are drawn in with cooling waters. The effects can be severe if facilities using cooling waters are located in estuarine spawning and nursery areas of fish or shellfish. The eggs, larval stages, and juvenile forms of these species are found in the water and may be killed by passage through a cooling system (Clark and Terrell, 1978; Clark, 1977). For example, up to 165.5 million menhaden (a marine fish of the herring family) larvae were killed each day by entrainment at the Brayton Point Power Plant in Massachusetts during the summer of 1971. At the same plant fifty million fish were killed in 11 days. Another power plant, located along the Hampton-Seabrook Estuary in New Hampshire, was responsible for the entrainment and subsequent death of 74 million clam larvae per day (Boreman, 1977).

Screens used to keep debris out of the cooling water intake often act as a trap for marine and freshwater organisms. When cooling waters are drawn into a plant, fish and other aquatic organisms may become entrapped or impinged on the intake screens resulting in damage or death from starvation, exhaustion, and asphyxiation (Barnes, 1976). During the fall of 1972, six million herring were killed by impingement on the screen of a cooling water intake structure at a power station on the James River in Virginia (Clark and Brownell, 1973). At the Oyster Creek power plant in New Jersey, approximately 10,000 fish and 5,000 crabs per month were destroyed by impingement during the spring and summer of 1971. About 400,000 fish and 10,000 shellfish are killed by impingement annually at a power plant near Cedar Key, Florida (Boreman, 1977). Fish attracted to the warmer waters may be unable to escape the strong currents generated by the intake, and may be drawn to and suffocated on the intake screens where water enters the cooling systems (Clark, 1977). At the Indian Point power station in the Hudson River estuary, thermal attraction appeared to contribute to high winter screen kills of fish and other aquatic organisms (Clark and Brownell, 1973).

Fish and other aquatic organisms can also be trapped in intake channels where screens are set back into the channel. Entrapment can occur because species cannot overcome the current and leave the system (velocity entrapment), or because species will not leave the channel (behavioral entrapment). Entrapped fish will remain in the intake channel until they tire or otherwise become impinged on the intake screens. Juvenile fish and larval stages are most likely to be entrapped by current velocities in intake structures. Behavioral entrapment can occur if fish are attracted to currents present in the intake, if the opening to open water is small compared to the size of the channel, and if a "skimmer wall" is present to allow water withdrawal from under the ice. Pelagic species entering the intake channel under such a wall may not be able to escape because their midwater behavioral adaptions may not allow them to find the low entrance (U.S. Army Corps of Engineers, Alaska District, 1980).

Thermal pollution resulting from the discharge of heated effluent water into marine waters can affect the entire aquatic ecosystem. The amount of damage caused by the discharge of cooling waters will depend on 1) temperature of the discharged effluent, 2) the volume of discharged waters, and 3) the size and flushing characteristics of the water basin which the cooling waters are withdrawn from or discharged into. Animal behavior including feeding, spawning, migration, and predator-prey relationships may be altered. The amount of damage inflicted upon the natural life patterns and the behavior of aquatic species depends on the size and flushing characteristics of the receiving waters and the amount and temperature of the discharged effluent. If water temperatures are changed, species that cannot tolerate these alterations may be killed or will relocate. Desirable species may be replaced by more tolerant, but less desirable species. The species of fish and shellfish found in Alaskan waters are generally adapted to a fairly narrow temperature range, and may be killed by temperature changes of 1-2 degrees Celsius (2-3 degrees Farenheit). Zooplankton drawn in with cooling waters at a nuclear power plant on the Connecticut River were all killed when passed through the cooling condenser at temperatures above 31°C (88°F). Mortalities were attributed to heat shock (Massengill, 1976). Other species become acclimatized to the warm effluent plume created by the discharge of cooling waters and die of thermal shock when the system is shut down for maintenance or when temperatures are altered (Clark, 1977). In laboratory tests, 50% of the juvenile sockeye and coho salmon tested died when temperatures were dropped from 5° to 0°C (41° to 32°F). When a power plant on the Susquehanna River in Pennsylvania was forced to shut down during winter, the temperature in the mixing zone dropped from 26.7° to 2.2°C (80° to 36°F) killing an estimated 23,178 fish which had congregated in the warmer waters. Thermal effluents also have a critical effect on seagrasses such as eelgrass. All seagrasses appear to have upper and lower temperature tolerance levels. The upper level for eelgrass is 30° Celsius (86°Farenheit). Above these levels, leaf kill and plant death set in. Jay Zieman of the University of Virginia and Anitra Thorhaug of Florida International University have documented the extensive damage done to another seagrass, Thalassia sp., in Biscayne Bay by heated effluents from two fossil fuel and two nuclear power plants at Turkey Point. Discharges from the plants raised water temperatures in the nearby waters of Biscayne Bay 5°C (9°F) above the ambient temperature. All plants in an area of about 9.3 hectares off the mouth of the discharge canal disappeared, while those in an area 30 hectares farther out declined by about 50 percent. The animal communities associated with these meadows also disappeared (Phillips, 1978).

Cooling systems tend to become fouled with algae, bacteria, and planktonic life and may lose their efficiency. Chlorine and other algacides are added to the water and flushed through the system to kill these organisms (NERBC, 1976). Unfortunately, chlorine and the chloramine compounds which are formed when chlorine enters fresh and marine waters are extremely toxic to fish and other marine life. The death of fish exposed to chlorine and its related compounds has generally been attributed to damage of the epithelial cells of gills, resulting in ultimate suffocation of the fish (Tsai, 1975). It is probable that chlorine affects other marine organisms similarly. Holland et al. (1960), indicated that chinook salmon started to die in sea water containing 0.25 mg/l of chlorine. The maximum non-lethal (in 23 days) concentration of residual chlorine for pink salmon and coho salmon in sea water was 0.05 mg/l.

Taylor and James (1928) reported that 0.3 mg/l of free chlorine killed rainbow trout in two hours and that 0.25 mg/l proved fatal to fingerling trout in four to five hours, but had no effect on goldfish in 42 hours. Conventry et al. (1935) indicated that some delicate species of fish are sensitive to residual chlorine or chloramines as low as 0.05 mg/l. Concentrations of 0.01 mg/l with maximum 0.06 mg/l chlorine are fatal to trout fry in 48 hours. Tsai (1973) indicated that if all species of fish are to be protected in areas immediately below sewage outfalls, the standard would be no detectable total residual chlorine in the discharge.

Chlorine also is known to affect fish behavior. Dandy (1967, 1972) showed that exposure of brook trout to chlorine evoked changes in activity, ventilation, the coughing reflex, and at lethal levels, a heavy secretion of mucus. Locomotory activity increased initially and was subsequently depressed. Both responses were seen at 0.35 and 0.08 ppm, but at the sublethal level of 0.005 mg/l, the initital increase in activity was not seen.

Tsai (1970) found that chlorinated sewage effluents became an ecological barrier, blocking upstream migration of semi-anadromous white perch and white catfish, and potamodromous white sucker and northern redhorse in the Patuxent River, Maryland. It is probable that chlorine contaminated effluents from cooling water discharges will have similar effects on salmon and marine fish migrations.

Very little information is available on the effects of chlorine and chloramines on other marine organisms; however, they are probably very harmful, especially to sessile organisms which cannot avoid the effluent. Muchmore and Epel (1973) found that unchlorinated domestic sewage is a relatively mild inhibitor of external marine fertilization in three species of marine invertebrates. Chlorinated sewage is a very potent fertilization inhibitor, active in concentrations as low as 0.05 mg/l available chlorine. Primary effects of both chlorinated and unchlorinated sewage are on sperm. Use of chlorine disinfection in cooling waters outfalls could also contribute to reproductive failure in external fertilization of marine invertebrates in the vicinity of the initial diluting water of such outfalls.

Cooling waters can also become contaminated by hydrocarbons or petrochemicals leaking into the cooling system. These toxic substances can also cause disturbances to aquatic organisms in receiving waters (NERBC, 1978).

Water Withdrawal

Water is a necessary component of petroleum development. Although much of the water is used for cooling, water is also required for hydrostatic testing, drilling, maintenance of roads, waterflooding and domestic use (USGS, 1979). The Prudhoe Bay waterflood project was designed to withdraw 4.07 m^3/s (64,200 gal/min) from coastal waters (U.S. Army Corps of Engineers, Alaska District, 1980). Domestic water requirements can range from 283 to 756 liters (75 to 200 gallons) per day/per person (USGS, 1979).

Because of limited water resources, marine waters will be used for large scale water withdrawals such as for waterflooding. Impacts of these withdrawals will be similar to those described previously for cooling waters. For smaller water requirements and where fresh water is required, rivers, lakes, streams or man made storage areas may be used.

Natural freshwater sources are limited in the Norton Sound-northern Bering Sea region. There is a lack of surface runoff due to low precipitation, the presence of permafrost, and numerous low mountains. Peak flows in streams typically occur in May through August with minimum flows occurring from December through March. Ground water sources (for wells) are primarily available beneath channels of larger streams and adjacent to large lakes (Hanley et al., 1980).

The magnitude of impacts caused by water withdrawals will vary according to season. In summer, if water withdrawals are spread out over several rivers or other large water bodies, impacts will probably be limited to small erosional problems at sites where the withdrawal occurs. Entrainment of aquatic organisms will occur but can be limited by proper design and screening of intake structures. Use of water from small to medium arctic streams during the fall can be particularly deleterious, as the habitat of aquatic organisms and fish is altered, and normal water levels are not restored until the following spring. Withdrawing water from streams without adequate recharge rates can lower water levels, affecting fish spawning areas and other important aquatic habitats. During the winter, flow rates in all arctic streams decline to a fraction of summer levels, and the remaining overwintering habitat for fish and other aquatic life is comprised of a series of pools connected by minimal under ice and intergravuler flows. In winter, removal of water from stores beneath ice may create several ecological problems. If all water is withdrawn from an area supporting aquatic organisms, all of the organisms living in that habitat will die. When some of the water is removed, organisms crowded into the remaining volume may cause a buildup of waste metabolites or a decrease in dissolved oxygen concentration due to respiratory activities. Partial removal may also dewater gravels which contain developing fish embryos (USGS, 1979).

Table 38 Effects of cooling waters and water withdrawals on fish, wildlife, aquatic plants and their habitats

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
FISH				
Acute/Toxic Effects				
Juvenile Salmon (Oncorhynchus spp.)	Smith et al., 1969	unknown	impingement	The injury rate resulting from scale loss was inversely proportional to fish size (i.e., small fish are affected greatly by scale loss). For salmon (Oncorhynchus spp.) less than 30 cm. in length, death occurred three to eighteen hours after 30-50 percent scale loss. In addition, fish behavior after scale loss was observed to change markedly. One hour after descaling, juvenile salmon were noticeably less active and less alert to visual stimuli than were controls. Loss of equilibrium occurred approximately three hours after descaling, followed by a decrease in respiration and activity. In general, death occurred approximately four hours after descaling. The time sequence varied with the severity of scale loss. Loss of body weight followed descaling in marine species, presumably as the result of osmotic removal of water and body fluid through the injured skin surface and the gills.
Herring (Clupea harengus)	Clark and Brownell, 1973	literature review	impingement	Six million herring were killed by impingement on the screen of a cooling water intake structure at a power plant on the Thomas River in Virginia.
Menhaden larvae (Brevoortia sp.)	Boreman, 1977	literature review	entrainment	Up to 165.5 million menhaden (marine fish of herring family) larvae were killed per day by entrainment at the Brayton Point Power Plant in Massassachusetts during the summer of 1971. At the same plant 50 million fish were killed in eleven days.
Larval Fish (Lagodon rhomboides) (Paralichthys sp.) (Brevoortia tyrannus) (Mugil cephalus)	Hoss et al., 1974	laboratory tests	entrainment	Conditions of entrainment were simulated in the laboratory to investigate the effects of thermal shock, the combined effects of thermal shock and copper, and the combined effects of thermal shock and chlorine on the survival of larval fish. A cycling acclimation temperature was found to reduce the effects of themal shock on larval pinfish, Lagodon rhomboides. Survival of pinfish held for twenty four hours in water containing 1.0 ppm copper prior to thermal shock was significantly reduced at shock temperatures of 12° and 15° above acclimation temperatures. Flounder, (Paralichthys sp.) Atlantic menhaden, (Brevoortia tyrannus) striped mullet, (Mugil cephalus) safely withstood limited exposure to 0.3 ppm chlorine at ambient temperature: up to five minutes for mullet and flounder, and up to seven minutes for menhaden. Reductions in survival occurred at exposures longer than the above, and further reductions occurred with the addition of heat. Survival was reduced still further at chlorine concentrations of 0.5 ppm, in some cases at ambient temperatures. The experiments indicate that the interaction between heat and chlorine is synergistic.

LC50 = concentration required to kill 50% of the test animals
LT50 = temperature required to kill 50% of the test animals

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Fish	Pavlov and Pakhorukov, 1973	literature review, laboratory and prototype studies	entrainment	Work in USSR on fish bypass systems showed that using fine mesh fish diversion screens, and depending upon approach velocity and bypass flow, bypass of 10-40 mm (0.4-1.6 in) fish could be achieved with up to 97.6 percent efficiency.
Fish	Taft et al., 1976	field observations	entrainment	Studies of bypass by fish 25-150 mm (1-6 in), were conducted for a number of large power plants. It was found that an angled 9.5 mm (3/8 in) screen oriented at 25° to the flow was able to bypass 100 percent of the fish tested. Of the fish bypassed, there was 96 percent one-week latent survival.
Fish Larval fish	Ray et al., 1976	literature review	entrainment impingement	Mechanisms and intake designs for reducing the number of fish entrained and impinged at water intake facilities were evaluated. Special consideration was given to designs that protect small fish and larvae. The conclusions were: (1) although several successful applications of electrical, air, and lower barriers have been reported, behavioral barriers in general showed limited applicability to power plants, (2) high savings of impingeable-sized fish were reported with a vertical traveling screen with attached water carrying troughs to lift fish from the screen wall as the screen continuously rotates, (3) most power plant screens are incapable of protecting larval fish, and (4) plant siting in least productive areas is viewed as the most important consideration in terms of mitigating fish loss.
Fish	Tomljanovich et al., 1977	unknown	impingement	The author found a strong inverse relationship between impingement duration and survival, particularly for impingement times in excess of four minutes.
Post larval and juvenile Menhaden Spot (<u>Brevoortia tyrannus</u>), (<u>Leiostomus xanthurus</u>), and pinfish (<u>Lagodon rhomboides</u>)	Hoss el al., 1971	laboratory studies	entrainment thermal shock	The critical thermal maximum (the temperature at which an animal loses its ability to escape from conditions that will kill it) for post larval and juvenile menhaden, spot, and pinfish acclimated at 15°C was 29.4°, 31.0°, and 31.0°C respectively. Oxygen consumption increased as temperature increased indicating additional environmental expenditure was necessary to maintain the fish at elevated temperatures. At temperatures of 15°C above normal environmental temperature, all of the menhaden, spot, and pinfish died within five to ten minutes. When first placed in the test tank, all fish were quiet. Increased temperature caused in succession: rapid swimming; spasms; flaring or spreading of the opercula, and; finally death.
Fish	Hoss et al., 1979	literature review	thermal pollution	The use of weekly average temperatures as the basis for determining safe discharge plume temperatures during cold months may not provide enough protection if the plume temperature fluctuates widely enough during the week to permit fish in the plume to become acclimated to a temperature significantly higher than the average weekly plume temperature. Knowledge

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
				of rates of acclimation in fishes is rudimentary and based almost entirely on constant temperature exposures rather than on exposures to cyclic or variable temperatures. However, the evidence generally indicates that acclimation to an elevated temperature proceeds more rapidly than does acclimation to a lower temperature, and therefore that thermal tolerances of fish exposed to fluctuating temperatures tend to correspond to the maximum rather than the average temperature experienced during acclimation. Thus during the cooler months the average weekly temperature in a given discharge plume might be lower than the temperature to which fish in that plume are acclimated; this could result in unanticipated low temperature mortality as a result of interruption of heat discharge, even though the average plume temperature during the period of heat discharge was carefully regulated (on the basis of reliable information on the lower lethal threshold temperature of the organism of concern) to prevent low temperature mortality.
Larval Sockeye Salmon (Oncorhynchus nerka) larval Coho Salmon (Oncorhynchus kisutch) and larval Atlantic Herring (Clupea harengus)	Becker et al., 1977	literature review	thermal discharge thermal shutdown	The cold shock resistance of acclimated freshwater juvenile sockeye and coho salmon and estuarine larval Atlantic herring during thermal shutdown was tested. Fifty percent mortality occurred when the temperature was reduced (acclimated to ambient) from: 5° to 0°C, 10° to 3°C, 15° to 4°C, and 20° to 5°C for juvenile sockeye salmon; 5° to 0°C, 10° to 2°C, 15° to 3.5°C and 20° to 4.5°C for juvenile coho salmon; and 7.5° to -1.75°C, 11° to -1.5°C, and 15° to -0.5°C for larval herring. Resistance to cold may vary with salinity for marine and estuarine species.
Northern Pike (Esox lucius) and other fish	Becker et al., 1977	literature review	thermal discharge shutdown	When a power plant on the Susquehanna River in Pennsylvania was forced to shutdown during winter, the temperature in the mixing zone dropped from 26.7° to 2.2°C. The drop in temperature killed an estimated 15,388 "valued" fish congregating in the warmer water. The fish affected were walleye (Stizostedion vitreum), smallmouth bass (Micropterus dolomieui), muskellunge (Esox masquinongy), northern pike, and various panfish, catfish and suckers. An additional 7,790 carp (Cyprinus carpio) also died.
Northern Pike (Esox lucius), and Spottail Shiners (Notropis hudsonius)	Becker et al., 1977	literature review	thermal discharge shutdown	About 250,000 spottail shiner and 250 northern pike were destroyed by thermal shock when a mechanical failure forced an abrupt power plant shutdown in Alberta, Canada, and the temperature in an extended discharge canal dropped 16.9°C in a 30 min span.
Bluegill Sunfish (Lepomis macrohirus)	Speakman and Krenkel, 1972	unknown	thermal discharge shutdown	Temperature change rates permitting survival of bluegill sunfish were examined experimentally. Rates of increase causing mortality were at least 20 times as rapid as corresponding rates of decrease, indicating that bluegill compensated more rapidly for increasing temperatures than for decreasing temperatures. Decline rates providing 50 and

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
				90 percent survival during cooling were: 1) -0.19° and -0.15°C /hour for 25° to 5°C range, 2) -0.072° and -0.053°C/hour for 30° to 5°C range, and 3) -0.32° and -0.16°C/hour for 30° to 10°C range, respectively. If the change from higher temperatures was abrupt (such as would occur if the fish moved out of the thermal plume), the lower terminal temperatures of 10° and 5°C would have proven lethal.
King Salmon (Oncorhynchus tshawytscha) Pink Salmon (Oncorhynchus gorbuscha) Coho Salmon (Oncorhynchus kisutch)	Holland et al., 1960	unknown	chlorine	The maximum non-lethal concentration (for 23 days) of residual chlorine for pink salmon and coho salmon in seawater was 0.05 mg/liter. Concentrations of 0.25 mg/liter of chlorine were lethal to king salmon.
Juvenile Pink (Oncorhynchus gorbuscha) and King Salmon (Oncorhynchus tshawytscha)	Stober and Hanson, 1974	bioassay	chlorine	King and pink salmon juveniles were tested in residual chlorine concentrations (the concentration remaining after the chlorine demand of the receiving seawater had been exceeded). For king salmon juveniles the LC50 was 0.5 mg/liter residual chlorine when tested at the mean ambient temperature of 11.7°C for exposure times of 7.5 and 15 min. A decrease in the LC50 to 0.25 mg/liter chlorine was found after 30 and 60 min exposures. Average increased temperatures of 2.6°, 4.9° and 10°C above ambient for 7.5, 15, 30 and 60 min exposures reduced the LC50 to 0.1°, 0.1°, 0.05°, and 0.05° respectively. The LT50 was reduced by about a factor of 10 with the increase of 10°C at 0.5 mg/liter residual chlorine after 7.5, 15 and 30 min exposures. The LT50 was reduced by about a factor of 5 with a 10°C increase in temperature at 60 min. The LT50 generally decreased with exposure at each test temperature. Mortality occurred after the 7.5 and 15 min exposures while fish were "recovering" in ambient sea water; however, the 30 and 60 min exposures were sufficient at the higher test temperatures to cause an LT50 within the exposure period. The 60 min exposure was the most acutely toxic to king salmon. For pink salmon juveniles, the LC50 was 0.5 mg/liter residual chlorine when tested at the mean ambient 13.6°C at 7.5 min exposure and decreased to 0.25 mg/liter chlorine at 30 and 60 minute exposures. Average increased temperatures of 5.0° and 9.9°C above ambient after 7.5, 15, 30 and 60 min exposures resulted in LC50 concentrations of 0.5, 0.1, 0.1 and 0.1 mg/liter residual chlorine, respectively. An increase of 9.9°C caused the LT50 to decrease by about 70 times at the 7.5 min exposure and about 3 times after 15, 30 and 60 min
Salmonids (Oncorhynchus sp.), Freshwater and Marine Organisms	DeGraeve et al., 1979	literature review	chlorinated cooling water	The authors recommend that the EPA criteria for continuous exposure to residual chlorine be lowered from 10 ug/liter to 3-5 ug/liter for marine and freshwater species other than salmonids. The EPA criteria for salmonids was set at 2.0 ug/liter and recent 96-hr flow through studies have shown that some freshwater species are more sensitive than salmonids, however, equipment sensitive enough to measure these levels is not widely available.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Rainbow trout (<u>Salmo gairdneri</u>) Codfish	Taylor and James, 1928	bioassay	chlorine	Concentrations of 0.3 mg/liter of free chlorine killed rainbow trout in two hours and 0.25 mg/liter proved fatal to fingerling trout in four to five hours. No effect was seen on codfish in forty-two hours.
Fish, Trout	Coventry et al., 1935	unknown	chlorine	Some species of fish are sensitive to residual chlorine or chloramines as low as 0.05 mg/liter. An average of 0.01 mg/liter with maximum of 0.06 mg/liter chlorine are fatal to trout fry in 48 hours.
Steelhead (<u>Salmo gairdneri</u>)	NWAFC, 1979a	field observation	water withdrawal	Extensive water withdrawals in combination with low water periods (drought or modest flow years) on the Columbia River has forced the trucking of steelhead smolts from upstream areas to safe release sites below Bonneville Dam. It was estimated that steelhead smolts migrating on their own suffered a 93% mortality. Low flows and resulting higher temperatures were thought to contribute to the mortality.
Freshwater and Anadromous Fish	Wilson et al., 1977	literature review	water withdrawal	Under-ice water depth is considered to be the single most important factor to fish winter survival. Fish must spawn and overwinter in portions of aquatic systems where unfrozen space is available and very low temperatures do not impair development of eggs. North of the Brooks Range ice thicknesses above overwintering pools of fish generally ranges from 1.5 to 3.0 meters. Overwintering fish are generally found where at least 2 meters of water remains unfrozen. However, fish have been found under ice in water depths as shallow as 0.4 to 0.5 meters.
<u>Physiological Effects</u>				
Fish Eggs, Larvae, Adults	Knapp, 1978	literature review	entrainment	Fish eggs, larvae, and adults caught in intake currents are exposed to: <u>Metabolic stress</u> from avoidance swimming. Fish larvae, juveniles and adults often attempt to overcome intake flows by swimming against induced currents. This behavior can severely stress respiratory, circulatory and muscular systems. It can cause the death of escapees -- the stress causing loss of equilibrium, increasing susceptibility of predation, and impaired feeding. Similarly, metabolic stress can contribute toward the mortality of organisms that do not escape and become entrained. <u>Mechanical abrasion</u> from contact with surfaces of intake system components and solids suspended in intake water. Circulating water pumps and condenser tubes are the primary sources of damage. Injury can be external or internal. External damage usually involves degradation or erosion of protective coverings -- membranes of fish eggs and larvae and scales of juvenile and adult fish. This damage often increases the organism's susceptibility to disease and parasites. Internal damage often involves hemorrhaging and rupturing of internal organs.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
				Mechanical forces occurring in the intake water. Organisms are exposed to three kinds of forces: hydrostatic pressure, acceleration, and shear. These forces can alter the organism's position in the water and exert stress on its external surfaces. If severe, such forces can cause substantial mortality among fish eggs and larvae. A variety of other stresses especially chemical and thermal pollution. Trauma or shock from one or more of the above effects. Impingement on intake screens cause death due to suffocation when the force of the intake water against the impinged fish closes the gill covers and inhibits breathing, mechanical abrasion, trauma, and shock.
Juvenile Salmon (*Oncorhynchus* sp.)	Prentice and Ossiander, 1974	unknown	impingement	The degree of oxygen stress observed in juvenile salmon impinged on intake screens increased with both increasing water velocity and increasing impingement time. Oxygen stress and a loss of equilibrium were evident in fish impinged 15 min at a water velocity of 61 cm/s. Reduced activity was evident in fishes forty-eight hours after impingement of 9 min or longer at a velocity of 61 cm/s. Survival decreased as the duration of impingement and water velocity increased. Minimum velocity at which internal hemorrhaging in juvenile salmon occurred was approximately 46 cm/s. At 61 cm/s hemorrhaging occurred in approximately 10 percent of the fish tested after a 30 sec impingement with an increase to 33 percent after impingement for 60 seconds.
Fish	U.S. Army Corps of Engineers, Alaska District, 1980	DEIS, literature review	entrainment, impingement	Tests with different mesh screens indicated that the body depth of a fish was the factor most responsible for determining if a fish was retained on a screen. Results of studies with 9.5 mm (3/8 in) woven square mesh screening indicated the fish smaller than 50 - 60 mm (2 - 2.3 in) in length would most likely be entrained. Fish over 100 mm (3.9 in) are usually retained on the screens. Fish between 60 - 100 mm in length (2.3 - 3.9 in) may fall into either category, depending upon general fish body shape and, in particular, body depth.
Fish	Hanson et al., 1977	literature review	impingement	Accumulation of debris on trash racks and intake screens tends to entrap and entangle fish, resulting in increased mechanical damage; and, alters the hydraulic flow field and approach velocities associated with each intake structure. High concentrations of suspended sediment abrade the eyes, gills, and epidermal tissue of impinged fish.
Steelhead (*Salmo gairdneri*)	NWAFC, 1980	laboratory and field tests	thermal discharge	Tests with 200 yearling steelhead showed an inverse relationship between survival and rearing temperature. Rearing temperatures above 10°C appear to retard smoltification and increase the incidence of external darkening.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Brook trout (*Salvelinus fontinalis*)	Dandy, 1967, 1972	unknown	chlorine	Exposure of brook trout to chlorine evoked changes in activity, ventilation, the coughing reflex, and at lethal levels, a heavy secretion of mucus. Locomotory activity increased initially and was subsequently depressed. Both responses were seen at 0.34 and 0.08 ppm of chlorine, but at the sub-lethal level of 0.005 mg/liter, the initial increase in activity was not seen.
Behavioral Effects				
Salmonid Fingerlings (*Oncorhynchus* sp.)	Prentice and Ossiander, 1974	field observation	entrainment	97 percent diversion of 70-170 mm (3-7 in) salmonid fingerlings was achieved in a fish bypass system using angled horizontal screens.
Fish	USEPA, 1976	unknown	entrainment	"Behavioral" entrapment in intake channels can occur even if water velocities are well within cruising speeds of affected fish. Setting screens back in the intake channel increases the potential for entrapment as does the use of a skimmer wall. Both channel walls and the skimmer wall create non-uniform velocities and entraping dead spaces. With the skimmer wall demersal species would be more likely to enter under the wall than pelagic species. However, if pelagic species enter the intake, they would be less likely to swim back under the wall. Potential for behavioral entrapment is also increased where the openings to the water source are small compared to the size of the intake channel. A fish guidance or bypass system was recommended as an alternative to approach channel intakes.
Fish	U.S. Army Corps of Engineers, Alaska District, 1980	DEIS, literature review	entrainment	Under certain conditions use of an air bubble curtain will deter fish from entering a water intake channel entrance. The effectiveness of the curtain as a barrier varies according to temperature, light intensity, and fish species. No change in impingement was observed in turbid water.
Fish	U.S. Army Corps of Engineers, Alaska District, 1980	DEIS, literature review	entrainment (avoidance)	15 cm/sec (0.5 ft/sec) was cited as the swimming speed attainable by many species of small fish and the mean cruising speed of all young salmon at low temperatures. Several species of cod and the longhorn sculpin had sustained swimming speeds greater than 15 cm/sec. Burst speeds (the highest speed a fish can attain for 20 seconds or less) showed little change with changes in temperature. However, some fish tested did not attain burst speeds of 15 cm/sec.
Estuarine Fish	Meldrim and Gift, 1971	laboratory studies	thermal discharge	Studies with 22 estuarine fish in Delaware showed that those fish actively avoided stressful thermal conditions although the temperature which would elicit an avoidance response was dependent upon acclimation temperature, light level, salinity and size of fish. Most of the same variables also affected temperature preference although small increases in temperature tended to attract fish.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
King Salmon (Oncorhynchus tshawytscha)	Gray, 1977	simulated thermal plume in raceway	thermal discharge	Juvenile king salmon tested under three discharge conditions (no plume, ambient plume, and heated plume) avoid plume temperatures greater than 9° to 11°C above ambient. The higher the temperature change, the more rapidly fish avoided the plume. Temperatures causing spasmodic contractions of somatic muscles were generally above 25.1°C. No evidence of thermal attraction was found. Authors felt that in some cases the avoidance response to higher temperatures could be used to cause fish to avoid a plume where other effluent components might work in combination with lower temperatures to cause mortalities or alter avoidance response.
Salmon (Oncorhynchus sp.)	Manzer et al., 1964	unknown	thermal discharge	The range of tolerable and preferred sea surface temperatures is different for each species of salmon in the Bering Sea and North Pacific Ocean, and these ranges change from spring through fall. Sockeye and chum salmon preferred the lowest sea-surface temperature range (2° to 9°C and 2° to 11°C respectively); pink salmon, the intermediate range (4° to 11°C); and chinook and coho salmon, the highest range (7° to 10°C and 7° to 12°C respectively). From May through July and August, all salmon species preferred increasingly higher temperatures. In September, all salmon species again preferred colder waters. In spring and early summer, maturing salmon were associated with slightly colder sea-surface temperatures than immature salmon. In late summer and fall, maturing salmon tended to be associated with warmer sea-surface temperatures. Tolerable ranges were found to be 1° to 15°C for sockeye, 1° to 15°C for chum, and 3° to 15°C for pink, 5° to 15°C for coho, and 2° to 13°C for chinook salmon. Criteria were provided for establishing tolerable limits.
Whitefish	Hoss et al., 1979	literature review	thermal discharge	Exposing young-of-the-year whitefish for one minute to elevated temperatures (2°C below their upper lethal temperature limits) made the test whitefish significantly more vulnerable to predation by yellow perch than control whitefish that had not been heat-shocked.
Fish larvae, Atlantic silverside (Menidia menidia) Summer Flounder (Paralichthys dentatus)	Deacutis, 1978	laboratory tests	thermal shock	Larvae of two fish species, Atlantic silverside and summer flounder, were subjected to a 15-min thermal shock of 10°C above acclimation temperature, returned to acclimation temperature, and exposed to a predator (striped killifish). Four- and six-week-old silverside were significantly more vulnerable to predation after being shocked than control larvae, but younger larvae were not. Shocked larvae of summer flounder were less susceptible to predation than control larvae.
Fish	Tsai, 1970	unknown	chlorine	Chlorinated sewage effluents became an ecological barrier, blocking upstream migration of semi-anadromous white perch and white catfish, and potamodramous white sucker and northern redhorse in the Patuxent River, Maryland.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Benthos				
Clam larvae	Boreman, 1977	literature review	entrainment	74 million clam larvae per day were entrained at the Hampton-Seabrook Estuary in New Hampshire.
Benthos	Esterly, 1975	field studies	thermal discharge	Numerical abundance, biomass, and species diversity of benthos were compared between two arms of a Missouri reservoir; the Hotwater Arm received thermal discharge while the control arm was at ambient temperature. Benthos, carried by currents, were deposited at the mouth of the Hotwater Arm, beneath the influence of the heated water. No direct effects of the heated water on the benthos were observed. However, numerical abundance and biomass were greater in the control arm than in the Hotwater Arm during the winter. There was no difference in species diversity between the two arms.
PLANTS				
Eelgrass	Phillips, 1978	unknown	thermal pollution	Upper temperature tolerance for eelgrass was cited as 30°C (80°F). Above 30°C, leaf kill and plant death occur.
Turtle grass (Thalassia sp.)	Phillips, 1978	unknown	thermal pollution	Extensive damage was done to a seagrass (Thalassia sp.) in Biscayne Bay by heated effluents from two fossil fuel and two nuclear power plants. Discharges from the facilities raised local water temperatures 5° above the ambient temperature. All plants in an area of about 9.3 hectares off the mouth of the discharge canal disappeared, while those in an area 30 hectares farther out declined by about 50 percent. The animal communities associated with these meadows also disappeared.
Eelgrass and Kelp Beds	Silvester, 1974	literature review	water withdrawal	Screens used to prevent entrainment of fish must be temporarily removed if storms bring in large patches of marine plants or other suspended matter that might clog the screens, restrict water flow, and within seconds create a fire hazard. A thorough knowledge of littoral currents, and siting of facilities in areas where currents will not transport uprooted marine plants near the intake, is suggested as the best answer to this environmental and safety problem.
OTHER AQUATIC ORGANISMS				
Acute/Toxic Effects				
Zooplankton	Massengill, 1976	unknown	entrainment	100% kill occured when zooplankton were passed through a cooling condenser in a nuclear power plant. Temperatures were above 31°C (88°F) and mortality was attributed to heat.
Fish and Aquatic Organisms	Clark and Brownell, 1973	literature review	impingement	Thermal attraction at a Hudson River power plant appeared to contribute to high (over 70%) winter screen kills of fish and other aquatic organisms. Fish were attracted to the warmer waters and suffocated on the intake screens.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Fish and crab, shellfish	Boreman, 1977	literature review	impingement	Approximately 10,000 fish and 5,000 crabs per month were killed by impingement at a New Jersey power plant during the spring and summer of 1971. At another power plant in Florida, 400,000 fish and 10,000 shellfish are killed annually.
Aquatic Organisms	Hoss et al., 1979	literature review	thermal pollution	Determining temperatures to which organisms are acclimated (when determining safe temperatures change limits) can sometimes be done by assuming that organisms are acclimated to the temperature of the water they are found in. However, this may not be the case (even in undisturbed habitats) where sharp thermal gradients exist, or where large diurnal thermal fluctuations may occur.
Aquatic Organisms	Knapp, 1978	literature review	chlorinated discharge	Many species of plants, invertebrates and vertebrates can be killed by chlorine concentrations greater than 1.0 mg/l total residual chlorine. Many fish species can be killed by concentrations above 0.2 mg/liters. Fish eggs and larvae are generally more sensitive to chlorine than adults. Some aquatic plants can tolerate concentrations as high as 10 mg/liter.
Physiological and Other Effects				
Zooplankton	King, 1974	field observation	thermal discharge	Comparison of the zooplankton populations near a power plant discharge and at a distant location on a Missouri reservoir showed significant differences. Cladocerans and larval copepods were more abundant at the heated site while rotifers were more abundant at the control site. No differences in zooplankton abundances were observed. Differences in species composition were only observed during population maxima. Timing of population maxima was not affected. Rate of growth for fish was less at the heated site. Temperatures at the heated site were 1.86° to 2.49°C above ambient.
Aquatic Organisms	Knapp, 1978	literature review	chlorinated discharge	Chlorine concentrations greater than 0.5 mg/liter can inhibit reproduction in some crustaceans (e.g., Gammarus pseudolimnaeus) finfishes (e.g., Pimephales promelas - fathead minnow), echinoderms (e.g., Strongylocentrotus purpuratus - sea urchin) and polychaetes (e.g., Phragmatopoma californica). Concentrations above 2.0 mg/liters can severely retard cell growth in plants, especially chlorophyta (green algae), chrysophyta (brown algae) and cyanophyta (red algae). Concentrations greater than 0.2 mg/liters can reduce growth in molluscs (e.g., Crepidula spp - gastropods) and fishes (e.g. Pimepheles promelas - fathead minnow). Reduced motility, evidenced by alteration of swimming (speed, duration and pattern) in finfish (e.g., Salvelinus fontinalis - brook trout) and pumping in shellfish (e.g., Crassostrea virginica - American oyster; and Ostrea edulis - European oyster) have been observed after contact with sublethal concentrations of residual chlorine.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Marine Invertebrates	Muchmore and Epel, 1973	unknown	chlorine	Unchlorinated domestic sewage was found to be a relatively mild inhibitor of external marine fertilization in three species of marine invertebrates. Chlorinated sewage is a very potent fertilization inhibitor, active in concentrations as low as 0.05 mg/liter available chlorine. Primary effects of both chlorinated and unchlorinated sewage are on sperm.
HABITATS				
Aquatic habitats	Knapp, 1978	literature review	cooling water	Water lost by evaporation, drift, and blowdown (the required bleeding off of water with high concentrations of accumulated salts from constant water evaporation) in cooling towers typically amounts to less than 4% of the intake requirement of an open-cycle system designed to dissipate an equal amount of heat.
Marine waters	Wolfson pers. comm.	field observation	cooling water	Cooling water used by the jack-up drilling platform Dan Prince in Norton Sound was 6° to 7°C (43° to 44°F) at the intake and 11° to 12°C (51° to 52°F) at the outfall. An estimated 1,250 gal/minute were used and discharged.
Estuary and Marine Waters	Trasky, 1977	unknown	water withdrawal	It was estimated that the proposed El Paso LNG plant's once through cooling system would require 658,000 gallons of seawater per minute or .95 billion gallons of water per 24 hour period.
Substrate, Currents	Knapp, 1978	literature review	cooling water withdrawal	Currents induced in front of cooling water intake structures can scour the bottom and degrade benthic habitat. Molluscan and crustacean shellfish, polychaetes, hydroids, insect larvae, attached periphyton, and rooted plants can be adversely affected. Induced currents can also disrupt natural circulation patterns around the intake structure, causing silting ahead of the intake forebay and producing a very unstable substrate. Benthic organisms can be adversely affected by smothering and increased turbidity. Elevated intake structures with low intake velocities (<1.0 fps) can eliminate or greatly reduce these problems.
Areas with Sluggish Circulation	Silvester, 1974	literature review	thermal discharge	Critical conditions for thermal pollution are more likely to occur in bays where tidal action or currents from freshwater flow are negligible than in well flushed areas. In stagnant bodies of water the sun can heat up the surface layer, so causing a density difference and strong stratification. When warm water discharge is poured into this surface layer it will not diffuse with water below the thermocline, where there is a significant change in temperature. Field measurements in Japan found a vertical diffusion coefficient on the order of only 0.01 m^2/sec whereas the horizontal value was 50 times greater. There was no evidence of turbulent mixing across the thermocline, which in many bays was 3 to 5 m thick. When no stratification occurred, mixing of warm effluent with the body of bay water occurred more rapidly. In such cases wave breaking generates turbulence at depth, whereas with a thermocline such mixing occurs only in the surface layer.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Bays and Estuaries	Silvester, 1974	literature review	thermal discharge	Heat accumulation in an estuary from cooling water discharge can affect chemical and biochemical processes, promote growth of flora, disrupt spawning cycles of fish, and in extreme cases increase evaporation and so increase salinity. Where intakes and outfalls must be located in close proximity, care must be taken that water is not recirculated in the system or the body of water being used becomes increasingly warmer.
Aquatic Habitats, Circulation	Knapp, 1978	literature review	cooling water discharge	Cooling water discharges can alter the physical and chemical properties of the water body affected. Subtle changes in the concentrations of nutrients, pollutants, and solids (suspended and dissolved) can occur around discharge structures as ambient and discharge waters mix. Alteration of the receiving water's circulation occurs as the momentum of low-velocity shoreline discharge and high-velocity subsurface discharge (i.e., diffuser) disrupts horizontal and vertical circulation in receiving waters. This can alter transport and distribution of organisms and nutrients near the outfall in some cases some distance away. Early lifestages of fish and benthic invertebrates can be carried to locations not suitable for growth and development. Alternatively, discharge can prevent movement of fish, especially migrants, along shore. Discharge can also simulate physical conditions similar to the introduction of a tributary into the main water body. This can elicit behavioral response in fish, especially migration and spawning, and cause fish to congregate in low velocity areas of discharge.
Aquatic Habitat, Atmosphere	Jolley et al., 1977	unknown	chlorinated cooling water	Chloro-organics, produced in low yields during the chlorination of once-through cooling waters at electric power-generating plants, consist of a large variety of compounds such as chlorophenols, chlorinated purines, chlorinated pyrimidines, and probably haloforms. Some of these products are toxic, and 5-chlorouracil is a mutagen for Escherichia coli. Little information has been found concerning the formation of chlorine-containing compounds in cooling tower waters. However, it is likely that haloforms, chloro-organics, and other chlorine-containing compounds should be generated during the repetitive cycling and chlorination of these cooling waters. Such compounds in cooling tower drift and blowdown could be environmentally significant.
Streams, Rivers	Grundy pers. comm., 1981	pers. observation	water withdrawal	When water withdrawal exceeds recharge rates during the winter, the ice cover collapses. Subsequent stream discharge does not refloat the concave ice sheet, but flows over the top, glaciating and causing a complete stream blockage. Glaciation can interrupt the flow of both surface and intergravel stream flow and dewater fish spawning and overwintering areas far downstream from the blockage.

Species/Habitat	Reference	Type of Study	Disturbance	Effect and Evaluation
Atmosphere, Vegetation	Knapp, 1978	literature review	cooling towers	Drift can be deposited downwind of cooling towers as a result of downdrafts and plume cooling and condensation. Drift droplets can contain dissolved and suspended solids present in intake waters which are concentrated by evaporative water losses, as well as residual components of compounds added for control of corrosion, scaling and fouling. Salt deposition from salt-water and brackish-water towers can cause damage to surrounding vegetation. Damage depends on the amount of salt deposited, the frequency of deposition, and the distribution of salt-tolerant and intolerant plants around the cooling towers. Direct foliar interception and uptake from contaminated soil are the principal pathways of exposure. The former is usually the most harmful, causing leaf lesions, marginal necrosis, defoliation, and even death. Water vapor introduced to the atmosphere increases relative humidity and can contribute to local increases in fog, icing, and precipitation.
Snowfall	Otts, 1976	field observations	cooling towers	Moisture and heat added to the atmosphere by large cooling towers in West Virginia appeared to contribute to heavy snowfall in localized areas downwind of the towers. Meteorological conditions were similar during the two events studied and included: a strong influx of cold air into the area, relatively high humidity, a strong inversion layer, and an average of minus 10°C or colder.

Sensitivity of Areas and Recommend Mitigative Measures

Areas in the northern Bering Sea and Norton Sound were ranked as having low, moderate, or high sensitivity to the impacts of cooling waters and water withdrawal (see Map H). These designations were based on available data and were made after evaluating the following criteria:

1. The sensitivity of each fish and wildlife species or habitat to cooling waters and water withdrawal.

2. The degree of sensitivity to cooling waters and water withdrawal which is experienced by each species during the various stages of its life history.

3. The time of year that these critical life history stages occur and the period during which each species would be most affected by cooling waters and water withdrawal.

4. The location of habitats where critical life history stages occur.

5. The productivity of the habitat.

6. The uniqueness of the habitat.

7. The species' population numbers and relative importance of the population.

8. The degree to which the impacts of cooling waters and water withdrawal could be mitigated.

Specific considerations and assumptions that were made during the course of ranking included:

1. Impacts of cooling water discharges and water withdrawal would be greatest in freshwater streams, lakes, wetlands, tideflats, shallow water areas, lagoons and bays. These habitats are generally highly productive areas that are unable to adequately dilute waters of higher than ambient temperature or sustain water withdrawals during winter low flow periods.

2. Eelgrass beds, kelp, and Fucus beds were assigned a high impact value because of their importance as fish nursery and spawning areas, as waterfowl feeding areas, and because of their sensitivity to heated water.

3. Aquatic species and species dependent upon riparian and wetland habitats are most vulnerable to mortality from cooling water discharges, entrainment or impingement in cooling water intakes, and by the effects of other water withdrawals.

4. Waterfowl staging areas were ranked as having a high sensitivity to the impacts of cooling waters and water withdrawals because of the dependence of these species on highly sensitive,

wetland habitats during critical life history stages. Degradation of a wetland's productivity by thermal pollution or through water withdrawals would substantially affect waterfowl populations using these wetlands.

5. Nearshore waters around St. Lawrence Island have been assigned a high sensitivity ranking based on known life history patterns of salmon and Arctic char. Although data specific to St. Lawrence is not available, Arctic char and juvenile salmon move into nearshore waters in the spring for feeding and rearing and remain in these waters throughout the summer.

6. Throughout most of the study area, the average seaward boundary of the shorefast zone was used as the boundary between areas ranked as highly sensitive and those ranked as moderately sensitive. Because the extent of the shorefast ice is affected by currents, it was felt that, until better nearshore current data is available, the edge of the shorefast ice could be used to identify where currents were strong enough to rapidly dilute thermal discharges (i.e. if the currents are strong enough to prevent shorefast ice formation, they should be strong enough to dilute discharges)

7. All marine waters in eastern Norton Sound not ranked as highly sensitive have been ranked as moderately sensitive because of reportedly sluggish circulation in the eastern

Sound and stratification of the water column during the summer. Rapid dilution of thermal plumes would be unlikely.

8. A "buffer" zone of moderate sensitivity was included off the Yukon River Delta and along the western Seward Peninsula seaward of high sensitivity nearshore waters.

9. Concentrations of demersal fish species such as Arctic cod, yellowfin sole, starry flounder, and saffron cod occur in waters where dilution of thermal plumes will occur rapidly; consequently, the impacts on these species are likely to be minimal. Entrainment of larval forms of these species in cooling water systems could have a major impact, however, areas of larval abundance are not known.

10. Impacts of cooling waters on offshore marine waters or in areas of strong currents would be minimal because of rapid dilution.

Sensitivity Designations and Mitigative Measures

LOW SENSITIVITY AREAS

Areas of low sensitivity are defined as those where impacts from open cycle (once through) cooling systems, closed cycle cooling systems and from water withdrawals would be less adverse than in moderate or high sensitivity areas. Such areas would include: 1) areas with currents of sufficient strength to adequately dilute thermal discharges; 2) areas with sufficient water reserves to maintain water withdrawals; and 3) areas with low numbers of sensitive species.

Facilities that use cooling systems in, or which require water withdrawals in low sensitivity areas should operate according to existing environmental regulations such as EPA (Environmental Protection Agency) and DEC (Alaska Department of Environmental Conservation) water quality standards, local zoning ordinances, and Coastal Zone Management guidelines.

MODERATE SENSITIVITY AREAS

Areas of Moderate Sensitivity are defined as those areas where the adverse impacts of cooling waters and water withdrawals can be prevented, minimized or ameliorated. Species or habitats within these areas are likely be moderately affected by cooling waters or water withdrawals.

Habitats identified as moderately sensitive include:

1. Region of sluggish circulation in eastern Norton Sound
2. A "buffer" zone around highly sensitive nearshore waters adjacent to the Yukon River Delta and the western Seward Peninsula.
3. Waterfowl and shorebird nesting, molting and staging areas including: major and important staging areas, emperor geese molting and staging areas, snow geese staging areas, swan nesting/use areas, sandhill crane use areas, and shorebird important habitats and fall staging areas.

Facilities using cooling systems or requiring water withdrawals within moderately sensitive habitats should conduct activities according to existing environmental guidelines and the following recommendations.

Cooling Waters - General

1. Closed cycle cooling systems should be used instead of open cycle (once through) cooling systems wherever possible. Closed cycle cooling systems cause fewer environmental problems than open cooling systems.

2. Before siting facilities which will use either closed cycle or open cycle cooling systems, site specific studies should be conducted to determine the location of vital habitats in the vicinity. Site specific oceanographic studies and bioassays should be conducted to determine the natural systems ability to absorb heat without biological damage.

3. Before choosing a site for a facility that will require a cooling system, a sound and comprehensive water management program should be developed to study: the supply of ground water, aquifer replenishment sources, the potential for contamination and depletion of waters, and the possibilities for reclaiming wastewater and minimizing unnecessary water withdrawals.

4. Cooling water channels should not be dredged through wetlands nor should natural creeks be used as cooling water conduits.

5. Screens on intake structures should not exceed 1 millimeter (0.04 inches) mesh size and intake velocities at the screens should not exceed 7.5 cm/sec (0.25 ft/sec).

6. Outfalls should be located in areas of rapid dilution and at an adequate distance from the intake so that water is not recirculated in the system.

7. The use of toxic chemicals to remove encrusted sealife in cooling systems should be avoided to prevent toxic impacts on recieving waters. Mechanical cleaning methods or heat treatment should be used instead.

8. Freshwater lakes, streams, or wetlands should not be considered as a water source for cooling waters, or sites for thermal discharges.

Closed Cycle Cooling Systems

1. The use of closed cycle cooling systems (such as cooling towers or spray ponds) is preferred over open cycle systems because they cause less environmental damage.

2. Only closed cycle cooling systems should be used in estuaries and other areas that are vital to the coastal ecosystem or have high biological productivity (see Map H). With this type of cooling, water is recirculated rather than being continuously withdrawn from or discharged into aquatic environments thereby reducing the volume of water needed.

3. To minimize entrainment of organisms, intake velocities should not exceed 7.5 cm/sec (0.25 ft/sec) at the surface of the intake screens and screen mesh size should not exceed 1 millimeter (0.04 inches).

4. Toxic chemicals (such as chlorine) added to cooling waters to reduce corrosion in cooling towers and growth of fouling organisms in condenser systems, should be collected and treated before being released to the environment. The chemicals can be reduced by treatment such as chrome reduction or precipitation using ferrous sulfate in a reducing pit. These hazardous wastes should be disposed of in a landfill site designated for hazardous wastes.

5. Normally, adverse effects of vapor plumes and salt fallout from closed cycle systems are significant only in the immediate vicinity of the plant and may be alleviated by locating plants appropriately with respect to climate and geography. Plants should not be located near important wildlife wintering areas and early spring use areas where additional snowfall could impact wildlife populations.

6. Among various types of closed cycle cooling systems, spray canals appear to cause less environmental damage than evaporative cooling towers, and should be used wherever possible.

Open Cycle Cooling Systems

1. Facilities that use open cycle cooling systems should not be placed in critical habitats nor in coastal areas such as wetlands, tideflats, and estuaries where waters for cooling would be withdrawn from or discharged into sensitive habitats.

2. Facilities using open cycle cooling systems may be located along the open coastline provided that the following criteria are used as guidelines during site selection:

   a. Facilities should not be located near estuaries (e.g., inlets, bays) where water is transported in and out by tidal action.

   b. Facilities should not be sited in or near vital or critical habitats found along the open coastline.

   c. Intake and outlet structures should be located offshore where discharges will be diluted and cooled more rapidly, and waters are not withdrawn from productive nearshore habitats.

   d. Intake and outlet structures should not be placed in areas of high biological productivity.

e. Cooling water intake and discharge points should be separated as widely as possible, taking advantage of water layering or other natural features to prevent recirculation of discharge water and the impingement of discharge-weakened fish on intake screens.

f. Cooling waters should be withdrawn from depths where water temperature is low enough that when discharged near the surface, the temperature of the surface water will not be greatly increased.

g. The temperature differential between waste cooling water the ambient water temperature should not exceed 1°C (1.8°F).

3. Open cycle cooling systems should be designed to limit the discharge of chemicals into the coastal ecosystem, provide for minimal disruption of natural water flow, and place intake and outlet structures for minimal effect on aquatic organisms. The following criteria should be used in the design of intake structures:

a. Systems should be designed to keep the velocity of inflow below a maximum of 7.5 cm/sec (0.25 ft/sec) at all points ahead of the intake screens and screen size should not exceed 1 millimeter (0.04 inches).

b. No successful device has yet been developed to divert fish larvae and eggs from the intakes of facilities using open cycle cooling systems. Much of the reported progress in this field is exaggerated and deceptive. (Minimal success has been made in diverting fish through fish by-pass systems).

c. All containing structures ahead of the intake screens such as forewalls, channels, bays, and recesses should be eliminated.

d. Intake structures should be located at depth and in locations of the absolute minimum concentration of biota.

4. Monitoring programs should be set up following plant construction to monitor system performance and the adequacy of mitigating measures. Suggested monitoring programs include: (1) frazil ice formation on the intake structure and outfall line; (2) impingement of organisms and ice on the intake screens; (3) entrainment of organisms in the intake system; (4) biofouling of the intake structure; (5) sea-ice level in relation to the intake structure; (6) intake velocities; and (7) the physical condition of fish in marine life return systems, and their fate and behavior after leaving the outfall (e.g. predation and disorientation).

5. Biocides should not be used to remove fouling organisms or should be removed from cooling water before discharge. Systems should be designed to use mechanical methods to remove fouling organisms.

Water Withdrawal for Purposes other than Cooling

Primary problems associated with withdrawal of fresh water for domestic, or industrial use are (1) entrainment and impingement of fish (both summer and winter) and (2) dewatering of stream channels and fish overwintering areas. Entrainment, impingement, and alteration of circulation patterns are the major problems associated with large withdrawals of marine waters.

Activities requiring water for other than cooling should be sited and operated according to the following criteria:

1. Large quantities of freshwater for domestic or industrial uses should not be withdrawn from any body of freshwater supporting fish.

2. No freshwater should be withdrawn from any body of water supporting overwintering fish.

3. When very limited amounts of water are required, use of several different water sources during the winter will lessen impacts on any one source.

4. When large amounts of water are required, storage facilities should be constructed to hold water collected during the summer for winter use. Abandoned gravel sites can be converted for water storage.

5. Water should not be removed from streams or lakes in excess of recharge rates. To do so causes collapse of the ice cover and stream blockage.

6. Water impoundment structures should not be built over permafrost. Melting of the underlying permafrost layer can result causing settlement and changes in drainage patterns.

7. Water wells should be carefully sited so that they do not deplete surface aquifers and dewater lakes and streams.

8. Wherever possible, water consumption should be reduced by water recycling. Examples include: recycling water from mud pits during drilling, and recycling domestic water for industrial uses.

9. When withdrawing water from marine areas, intakes should be designed to prevent entrainment of marine organisms or alteration of circulation patterns.

    a. Intake structures should be located at depth and in locations of absolute minimum concentration of biota.

b. Intake velocities should not exceed 7.5 cm/sec (0.25 ft/sec) at all points ahead of the intake screens. Intake screen size should not exceed 1 millimeter (0.04 inches).

c. All containing structures ahead of the intake screens such as forewalls, channels, bays, and recesses should be eliminated.

d. Intake structures should be designed so as to not funnel organisms into the intake (i.e. siting an intake at the end a long solid fill breakwater, jetty or causeway that extends into or across a fish migration route).

HIGH SENSITIVITY AREAS

Areas of high sensitivity were defined as those areas where the impacts of cooling waters and water withdrawals would be extremely detrimental to fish and wildlife resources. Habitats included in the high sensitivity category include:

1. Shorefast ice zone
2. Eelgrass and Fucus/kelp beds
3. Highly productive and heavily used wetlands and tideflats and wetlands and tideflats where productivity is not known.
4. Estuaries and lagoons
5. Salmon streams, nearshore migration areas and salmon fry nearshore rearing and feeding areas.
6. Arctic char and sand lance concentrations

7. Herring spawning, possible spawning, wintering, and nearshore feeding and rearing areas

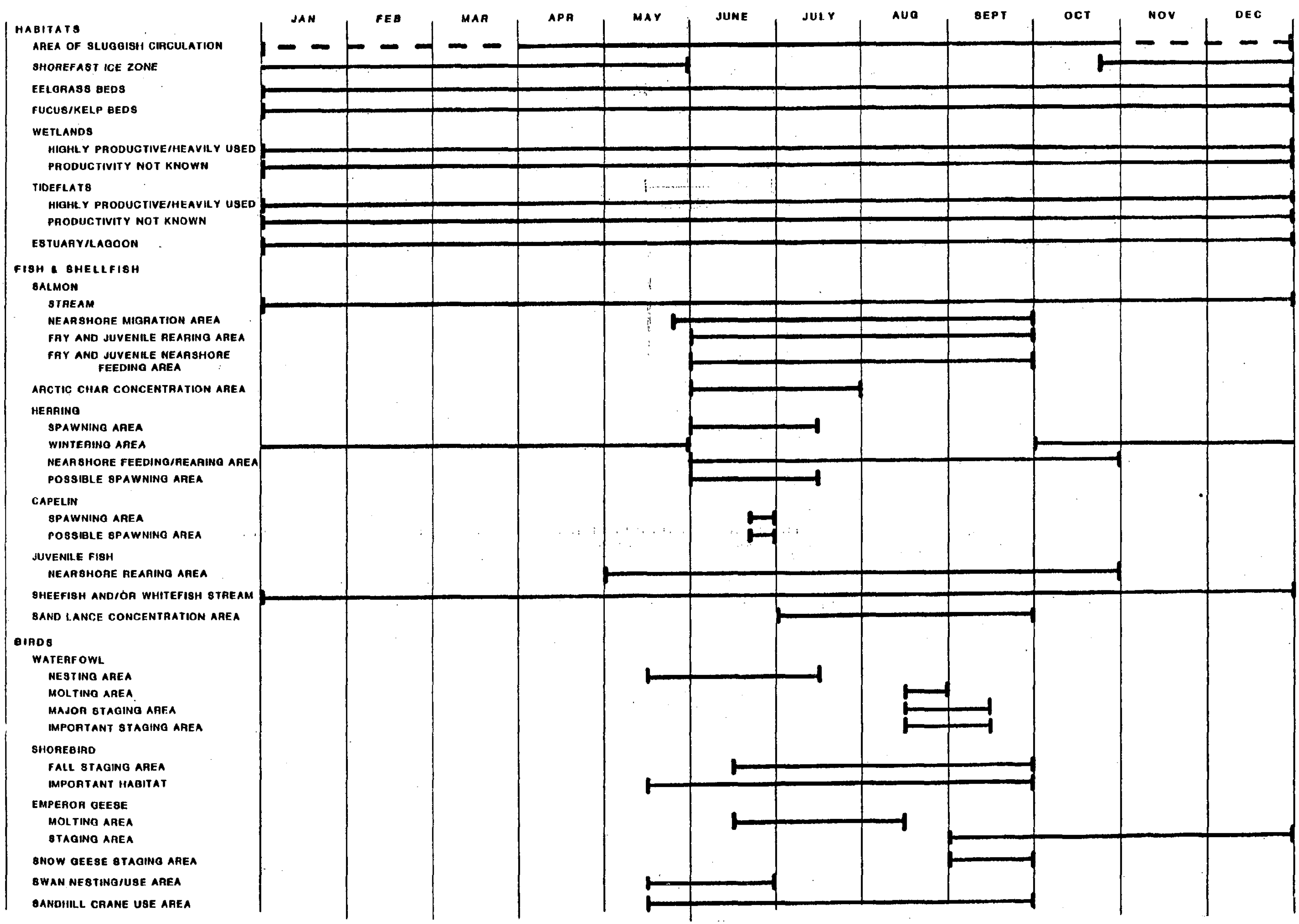
8. Capelin spawning and possible spawning areas

9. Juvenile fish nearshore rearing areas

10. Sheefish and whitefish streams

Facilities using open cycle (once through) cooling systems should not be sited in high sensitivity areas. Water withdrawal activities and facilities using closed cooling systems should be sited and operated according to the specific environmental guidelines found in the modereate sensitivity section.

TABLE 39 : MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND SPECIES OR HABITATS ARE MOST SENSITIVE TO COOLING WATERS AND WATER WITHDRAWAL.



I

COMMERCIAL & SPORT HARVEST

INTERFERENCE WITH SUBSISTENCE

INTERFERENCE WITH SUBSISTENCE, COMMERCIAL OR SPORT HARVESTS

Sources and Biological Effect

Due to the large amount of activity associated with the development of a major offshore oil field, conflicts are likely to occur between oil related operations and established fish and wildlife harvest activities. These conflicts can be classified into one of four categories: a) a localized increase in noise or physical disturbance which could cause wildlife to avoid areas where harvests normally occur, b) competition for space, labor, or limited fish and game resources, including the possibility of restricted access to harvest areas, c) physical loss or interference with fishing gear or vessels and, d) direct species mortality or area avoidance due to oil pollution.

Current Harvest Practices

Before attempting to describe the various aspects of harvest conflict, it might be advantageous to examine current harvest patterns and attitudes in the Norton Sound-Bering Strait region in order to acquire a broad understanding of the issues likely to be involved. The following discussion is taken primarily from the BLM/OCS technical report "Bering-Norton Petroleum Development Scenarios and Sociocultural Impacts Analysis", as prepared by Linda J. Ellanna:

The Norton Sound-Bering Strait region today is basically rural, isolated, and sparsely populated with abundant aesthetic values and relatively easy access to hunting, fishing, and recreational use of the sea and land. The core or central organizing principle which provides a basis for the sociocultural systems of a vast majority of residents in the study area --including those who have successfully integrated subsistence practices with a cash economy-- is subsistence.

Subsistence activities, particularly the hunting of sea mammals and fishing, are economically and nutritionally vital to the well-being of a large majority of Natives and a smaller percentage of non-Native residents. Contemporary subsistence practices in the Norton Sound-Bering Strait region can generally be subdivided into four subregional groupings based upon geographic proximity to various species and similar subsistence adaptations. These categories or patterns are as follows:

1.) <u>Small sea mammal hunting, inland hunting, and fishing pattern</u>: the contemporary communities of Shishmaref, Brevig Mission, Teller, and Mary's Igloo.

2.) <u>Large sea mammal hunting pattern</u>: the contemporary communities of Wales, Inalik (Little Diomede), King Island, Gambell, and Savoonga (St. Lawrence Island).

3.) <u>Norton Sound fishing and coastal and inland hunting pattern</u>: the contemporary communities of Solomon, Golovnin, White Mountain, Council, Elim, Koyuk, Shaktoolik, and Unalakleet.

4.) Yukon Delta fishing and small sea mammal hunting pattern: the contemporary communities of St. Micheal, Stebbins, Kotlik, Bill Moore's Slough, Hamilton, Emmonak, Alakanuk and Sheldon Point.

Several points relative to the above groupings should be made: (1) subsistence pattern titles are illustrative of major subsistence focuses and are not exclusive of other activities; (2) the city of Nome does not easily lend itself toward this type of categorization. Contemporary Native occupants of Nome come from a variety of communities and tend to follow the subsistence pattern of their place of origin if possible; (3) on the mainland, there are no abrupt subsistence pattern boundaries between the four major groupings but rather a continuum that may shift during certain years due to resource availability; and (4) the islands, due to their size and location, are more restricted in self contained resource variation but tend to have a more dependable and abundant subsistence base.

Due to the relative isolation of this region, there presently is not a large number of sport hunters or fishermen which utilize the area. An influx of people in conjunction with industrial development would undoubtedly create a real or perceived competition for the same animal resources. Most recreational harvests (hunting and fishing) occur off of the road systems leading from Nome, and are performed primarily by residents of that city (ADF&G, 1979a; Alt, 1979).

Commercial fishing to a limited extent is just beginning in the northern portions of Norton Sound and the Bering Strait. In the southern portion of Norton Sound and on the Yukon Delta, commercial fishing has gained increasing prominence each year (especially since implementation of the 200-mile U.S. fishing limit), and is the single major source of annual cash income to residents. Economic forecasts indicate that the full potential of the fisheries in this region have not yet been realized. Commercial harvests of Pacific salmon, Pacific herring, king crab, whitefish and Arctic char occur to a greater or lesser degree each year (ADF&G, 1979b).

Additional information regarding harvest practices, the amount and type of species harvested, and known harvest areas may be found in the harvest map (Map 8) accompanying this report.

Harvest Interference

In most harvest practices (perhaps hunting more than fishing) a certain amount of stealth must be employed in order to approach game animals. Noise or disturbance (including physical presence as well as visual, tactile, or olfactory inhibition) might significantly affect harvest success by frightening animals away or causing them to avoid an area during those periods when harvests typically occur. Some aspects of oil development which could contribute to elevated noise or disturbance levels and which would consequently impact harvest success include: seismic operation, aircraft or helicopter overflights, the operation of heavy machinery (e.g. bulldozers, graders, loaders etc.), the operation of small scale machinery (e.g. compressors, jackhammers, generators etc.), increased human presence, and increased vehicle or vessel traffic in traditional harvest areas. In addition, some activities may limit harvests by removing ground cover that might otherwise have attracted species or allowed hunter concealment, or may produce turbid water conditions which conceal species during periods of harvest (this is particularly applicable to belukha whale harvests which rely on visual tracking of animals in shallow water). For further information concerning the impacts of noise or disturbance on fish and game species (and therefore on harvests), see the Noise and Disturbance section of this report.

Another factor to consider when trying to anticipate harvest conflict is competition. Competition may occur through a variety of means, usually as a result of increased economic activity associated with oil development and the large influx of personnel required for such operations. In its tangible form, competition can be reflected in day to day situations where indigenous inhabitants of an area are gradually forced to compete with new residents or non-residents for a limited number of moose, waterfowl, or fish. Tangible competition may also include competition for limited services or goods such as harvest permits, dock space, fuel, or repair facilities and parts. Additionally, unless industry continuously acts to hold down lighterage costs for goods delivered to this region, inflated prices may restrict the purchase of harvest supplies (guns, ammunition, nets etc.).

Less tangible forms of competition, though not as obvious, may exert a greater debilitating influence on current harvest practices. An example of this would be the improper siting of activities or structures in a manner which might eventually deny access to traditional harvest areas. By physically inhibiting the free passage of fishermen or hunters, a corresponding reduction in harvest success might be expected, particularly if the prohibited area exhibited significant harvest value. A similar corresponding result might occur if State or Federal policies are implemented which allow industry to restrict access to vast acreages of leased public lands.

Extensive development will require a substantial workforce, especially during those periods when onshore support facility construction is most intense. It is likely that residents of this region will expect, and probably will receive hire preference over non-residents for unskilled labor positions. This may impact the local commercial fishery by removing a portion of its workforce. Terry et al., (1980) states: "The ability of the commercial fishing industry to respond to a decrease in the supply of labor is directly related to both the industry's ability to prepare for it and its duration. If there is little time to attempt to secure alternative sources of labor or to adopt labor-saving processing methods, the response will tend to be minimal, and the decreases in industry activity may be significant. The same will be true if the OCS impact on the price of labor is expected to be only temporary because the cost of responding may not be warranted by the temporary increase in the price of labor. In the extreme case, higher labor prices would make processing activities unprofitable, and processing activities would cease in the short run and perhaps also in the long run".

Harvest interference can also encompass the physical restriction or destruction of fishing gear. This may occur in numerous ways, and is most likely to affect fixed gear such as nets and crab pots, or marine fishing vessels which utilize heavy traffic corridors. Annually, a considerable amount of crab and fishing gear is lost or destroyed when vessels run through concentrations of this gear, cutting mooring lines and bouys. Seismic boats and tugs with barges are particularly bad offenders because of the large area covered by cables which extend behind such vessels.

In many instances the gear is not destroyed, but once the buoy is lost it is impossible to locate or recover the gear itself. In the case of king crab, derelict crab pots may continue fishing, killing untold numbers of crab before the metal rusts through completely and the trap ceases to be effective. If the vessel or vessels which cause gear losses cannot be identified, and typically they cannot be since the losses usually occur when pots are unattended, the crab boat sustaining the losses is not compensated and therefore bears the full burden of the lost gear and perhaps the full burden of the reduced income (Terry et al., 1980). Offshore pipelines may also entangle longlines, crab pots, and trawls if regulations do not require that they be buried or marked prominently.

In Norton Sound most marine fishing occurs in very nearshore areas and, as such, gear losses due to entanglement are expected to be minimized. However, debris from offshore drilling sites may physically foul nets, and some fishing areas may be eliminated completely by the filling of intertidal areas or the construction of onshore facilities. Furthermore, there may be increased incidents of vessel collisions if marine support activity generates higher levels of boat and barge traffic in near-coastal areas.

Oil and gas development may also interfere with fishing activities in the event of a major oil spill, or through persistent chronic oil pollution. Oil spills not only affect biological resources, but humans as well. In an area where a spill has occurred, fishing is usually suspended because fishermen do not want to foul their boats or fishing gear by using them in oily water (Nelson-Smith, 1973). As a result, overall fishing effort is reduced. Oil pollution may also reduce the number of fish and shellfish available to fishermen through direct mortality, or by causing them to avoid or abandon an area. Many species, such as Pacific salmon and Pacific herring concentrate in small areas along the coastline at specific times of the year, therefore contamination of these important habitats and the subsequent loss of these populations could have serious consequences for fishermen (Micheal, 1977).

Finally, oil pollution may produce tainting in the flesh of fish or shellfish. Fish in the area of a spill can acquire an oily or chemical taste making them unpalatable and undesirable for human consumption (Nelson-Smith, 1973). Even if no tainting has actually occurred, the public is often reluctant to purchase fisheries products from areas where there has been an oil spill, or areas which are known to be polluted. Tainting is discussed in greater detail in the section on Oil Pollution.

Sensitivity of Areas and Recommended Mitigative Measures

Harvest areas in the northern Bering Sea and Norton Sound were ranked as having a moderate sensitivity to the impacts of harvest interference (see Map I). Designations of low or high sensitivity have not been made since, 1) it is assumed that all identified areas of harvest exhibit some degree of value to the people that utilize them; 2) it is impossible to determine what types of development activities will occur in specific harvest areas at this time; and 3) importance is a relative term when applied to harvest (i.e., a harvest area may appear to be insignificant when compared to another which supports higher yields of species or greater numbers of users, however the original area may be extremely important to the few people which do rely on it).

In general, the impacts associated with harvest interference include:

1. Noise and disturbance associated with support facilities, machinery operation, aircraft and boats, seismic exploration, or human presence, which will drive subsistence, commercial or recreationally harvested species out of the range of fishermen and hunters.

2. Competition between indigenous fish and wildlife users and new workers for limited fish and game resources, hunting and fishing harvest permits, docking space, access to harvest areas, etc.

3. Physical interference with, or destruction of fishing gear.

4. Species avoidance of an area due to oil pollution, or the tainting of fisheries products.

Sensitivity Designations and Mitigative Measures

Mitigating measures in previous sections of this report have been proposed in an attempt to minimize development impacts on fish and wildlife populations and their habitat. It is assumed that impacts which affect species of subsistence, commercial, or sport value will also affect harvest levels. The following recommendations address impacts as they directly relate to current harvest patterns and practices.

Noise and Disturbance

Measures to minimize the effects of noise and disturbance have been discussed previously in the Noise and Disturbance section of this report, and are applicable toward minimizing harvest interference with the following additions:

1. Activities which produce turbid water conditions in important fishing and marine mammal harvest areas should either be scheduled during periods when they will not affect harvest practices, or should be designed so as to minimize the amount of suspended material present in the water column. Such activities would include dredging and filling, shoreline

alteration, gravel island construction, discharge of drilling muds and cuttings, etc.

2. The random or erratic operation of machinery, aircraft, boats or ATV's should be discouraged in harvest areas.

3. Exploratory drilling on lease tracts that are located on traditional fishing grounds should be scheduled during periods when fishing does not occur.

Competition for Resources

1. The Board of Fish and Game should anticipate potential harvest conflicts and should implement special game and fisheries management procedures or regulations which will serve to reduce competition between new workers and indigenous user groups.

2. In important subsistence areas the leasee should voluntarily limit the off-duty hunting, fishing, and trapping activities of its employees on leased lands.

3. When lease activities must be conducted in or near important harvest areas, the developer should arrange for community involvement in processes such as the siting of facilities, or the timing of activities, in order to minimize the adverse impacts of such operations on traditional hunting and fishing practices in the area.

Competition for Space

1. Leasees should not restrict public access to, or use of, leased public lands except in the immediate vicinity of development operations. Exceptions may be provided for in areas of extreme biological sensitivity.

2. Leasees should be sensitive to local industries and traditional vocations and should plan their activities to avoid impacting them. An example would be to insure that industry boats do not monopolize fish processing plant docks or staging areas.

3. The local coastal resource service area can identify separate and distinct areas for different kinds of economic activity through its coastal management plan. Where there is competition for a particular coastal site, the only solution may be a trade-off between conflicting parties. For example, an oil company might be convinced to locate a staging area away from an important harvest area in exchange for an offer of less expensive land or a zoning change.

4. During the site selection process for onshore and offshore facilities, leasees should avoid traditional harvest areas or sites which might block access to traditional harvest areas.

Physical Destruction or Restriction of Fishing Gear

Vessel Traffic

1. All development related marine vessel traffic including ice breakers should be required to travel point to point in a linear fashion, avoiding areas of marine harvest during periods when such harvests might occur. This would allow fishermen and hunters to predict where they might safely place their gear, or pursue marine mammals without disturbance.

2. Because high petroleum finds coupled with other forms of economic development (such as coal or offshore gold recovery operations) may make non-corridor vessel traffic extremely hazardous, permanent or recommended shipping corridors should be established based upon the following considerations:

   a. Maximum safety of all vessels utilizing limited navigational channels. Because of shallow waters and restrictive ice conditions, deep draft vessels may be forced to conform to relatively narrow natural corridors which, without regulation, will enhance the chances of collision.

   b. Minimum interference with traditional commercial or subsistence harvest areas.

   c. To provide an adequate buffer zone between vital habitat areas and vessel traffic.

d. Maximum public input.

3. Shipping corridors should:

a. Be clearly designated on marine charts.

b. Have adequate navigational aids such as buoys, beacons, and VTS (Vessel Traffic Safety) radar.

c. Have a reasonable speed limit established.

d. Be regulated, patrolled and enforced by the U.S. Coast Guard.

4. All oil tankers, LNG tankers, and other large vessels operating in the area must be required to use licensed pilots familiar with the northern Bering Sea - Norton Sound region, and with navigational problems in ice infested waters.

5. A reporting and communications system should be established for tankers and other large vessels utilizing the corridor system.

6. Permits issued to seismic boats operating in near coastal areas should stipulate:

a. Daylight operation only.

b. No operations within or adjacent to areas of concentrated commercial or subsistence fishing gear. Operations in these areas should only be scheduled during closed fishing periods.

c. If seismic surveys are absolutely unavoidable during periods when commercial king crab fishing occurs, cable length for seismic streamers should not exceed 1/4 mile in order to allow for adequate control in avoiding obstacles such as fishing gear.

d. Ship captains should report to the Alaska Department of Fish and Game, Area Management Biologist, for consultation on fishing gear concentrations prior to operating.

7. Commercial, subsistence or sport fishing vessels should not anchor, fish pots or trawl in zones designated as shipping corridors.

8. The Ports and Waterways Act of 1972 should be amended to designate mandatory shipping corridors.

Pipelines

1. To the greatest extent possible, pipelines should be routed around active bottom fishing or trawling areas.

2. Where the placement of pipelines in these areas cannot be avoided the following techniques should be utilized:

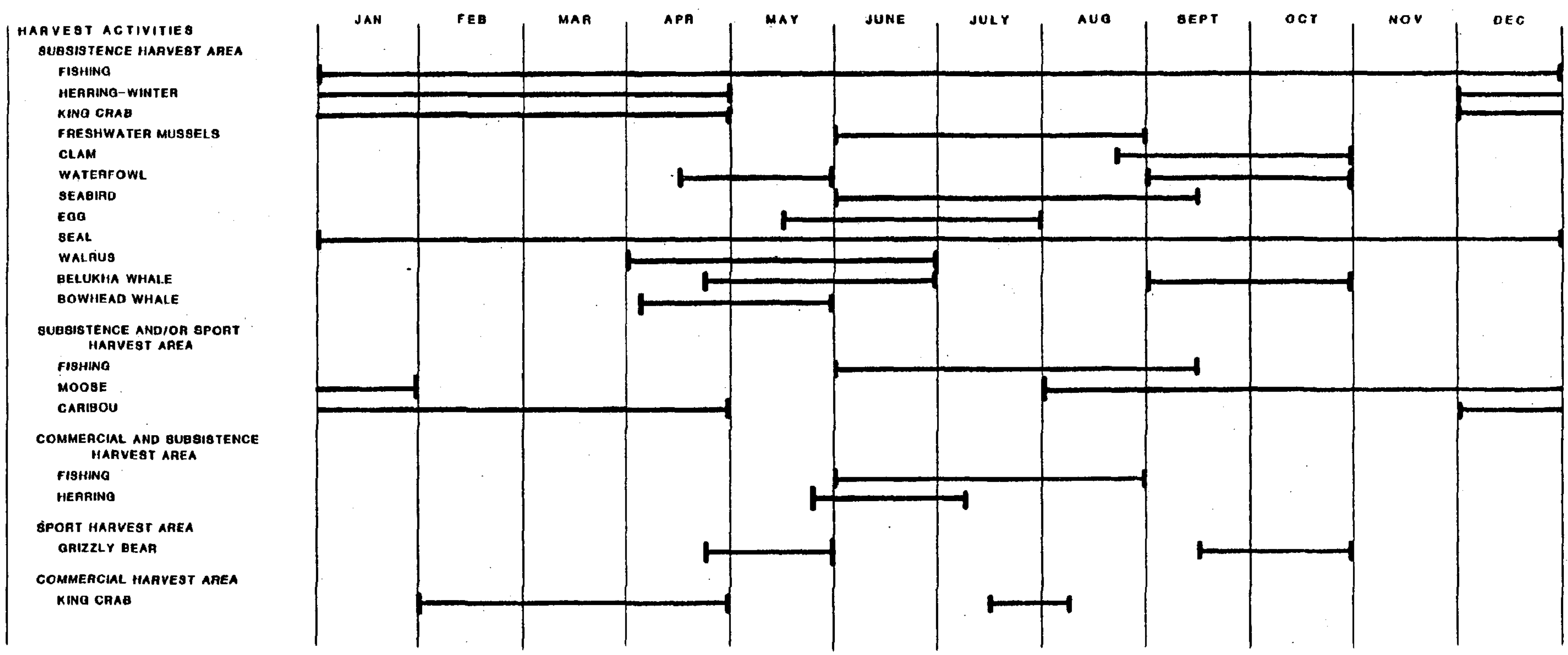
   a. Trenching - trenching should be used to bury pipelines beyond the point where they might entangle crab pots and anchors, be struck by trawl doors, or be ruptured by gouging ice keels.

   b. Pipeline route marking - unburied pipelines should be marked on navigation charts to discourage anchoring or trawling in those areas.

Oil Pollution - Avoidance and Tainting

Specific measures to minimize the impacts of oil pollution may be found in the Oil Pollution section of this report.

TABLE 40: MONTHS WHEN NORTHERN BERING SEA AND NORTON SOUND HARVEST ACTIVITIES ARE MOST SENSITIVE TO HARVEST INTERFERENCE.



J

SECONDARY DEVELOPMENT

SECONDARY DEVELOPMENT

Sources and Biological Effects

If commercially exploitable quantities of oil or gas are found in the Norton Sound-Bering Strait region, a variety of facilities will be required in order to begin development, production and transportation. Inevitably, with the establishment of onshore petroleum facilities an additional amount of secondary development will also be needed. Secondary development has two major components: indirect development, as typified by those industrial projects that serve and support the primary projects, often through sub-contracts; and induced development, the construction or expansion of community facilities and services (such as housing, utilities, transportation, schools, recreation and commercial facilities) to serve the added population which is attracted by employment opportunities in direct, indirect, and induced developments (Zinn, 1978).

Environmental disturbances from secondary development are primarily caused by construction activities and an increase in numbers of people. The construction of houses, buildings, roads, utility corridors, etc. will result in a direct loss of fish and wildlife habitat. Petroleum development scenarios for Norton Sound (Ender et al., 1980) anticipate an additional 387 to 485 houses will be needed for medium and high finds respectively; this would physically remove between 62 and 155 acres of land just for housing purposes. Although Nome would seem to be the most likely area to accomodate such additional development, in fact very little residential land is available and city expansion is limited due to surrounding patented mining claims. Therefore, future building sites must come from privately owned undeveloped land both within and outside of the Nome townsite, as well as city owned lots within Nome (Ender et al., 1980).

Some forms of secondary development, even with a maximum degree of consolidation, have the potential to disrupt a variety of species and their associated habitats. The construction and operation of electrical transmission systems are an example. These systems can require extensive right-of-way (ROW) cutting and clearing practices which may act to remove essential vegetational habitat or ground cover. The adverse environmental damages resulting from such practices include increased soil erosion and/or degradation, water quality degradation, air quality degradation if open burning is prescribed, and elevated noise levels. The effects of ROW construction on species may include temporary displacement or long term avoidance. Additionally, ROW corridors can provide access to non-native species resulting in increased levels of predation, competition, or incidence of disease and parasites (Knapp, 1978).

Clearing land for construction sites will result in the displacement of birds and mammals utilizing those areas. Animals which cannot tolerate disturbance will leave an area permanently and, if no equivalent habitat is available their numbers may be reduced (FERC, 1978). For example, the Collier Carbon and Chemical Corporation near Nikiski, Alaska, an industry using petroleum by-products to produce chemical fertilizers, is located in an industrial and residential complex where vegetation and habitat have been drastically altered in the past. As a result of this habitat disturbance wildlife use of the area which included species such as moose, brown and black bear, and other furbearers, is now minimal (Dames and Moore, 1976).

Additional impacts which may result from construction activities include: 1) surface and permafrost degradation resulting in the formation of sediment slump areas; 2) increased erosion which causes siltation in adjacent streams; 3) drainage pattern changes leading to vegetation changes; 4) increased dusting of both vegetation and snow, leading to early snowmelt and destruction of sensitive vegetation; 5) damage to the tundra surface adjacent to construction sites as a result of the operation of construction equipment; and 6) temporary or permanent blockage or hinderance to fish and wildlife movement (Gilliam, 1978).

The impacts of road construction include all of the problems listed above as well as some additional consequences. Roads will necessarily increase traffic and human presence in areas not previously subject to such intrusions, which in turn could promote harassment, injury, or death as animals venture near or across such road systems. Moose are frequent casualties of collisions with cars on Alaskan roads (FERC, 1978). In the Alaska Department of Fish and Game, Game Unit 14C (Anchorage), 93 moose were reported killed by cars in 1978 while 74 moose were reported killed by cars in 1979. In contrast, only 73 moose were actually harvested by hunters during those two years. Road kills between Talkeetna and the Knik River bridge accounted for 100 moose in 1978, while 50-60 moose are killed annually by cars between Skilak Loop Road and Kenai. By increasing human access, roads may also serve to reduce animal populations through expanded harvest levels and poaching. On the Seward Peninsula, hunting pressure along the road systems leading from Nome has been described as "intense", and in the past four years Nome residents have spent thousands of man-hours during each hunting season driving the roads in search of moose (ADF&G, 1979a).

Noise and disturbance associated with road systems will cause animals to avoid an area under some circumstances (Cameron and Whitten, 1978). Vehicles are percieved as both noisy and mobile, and dust raised by traffic can increase their apparent size. Furthermore, roads are frequently used by low-flying aircraft as an aid to navigation during periods of bad weather, which may provide yet another form of disturbance (Gilliam, 1978). If animals acquire a tendency to avoid road systems then roads have the effect of parceling those species habitats, restricting their range, and perhaps inducing added competition for species forced to utilize limited resources.

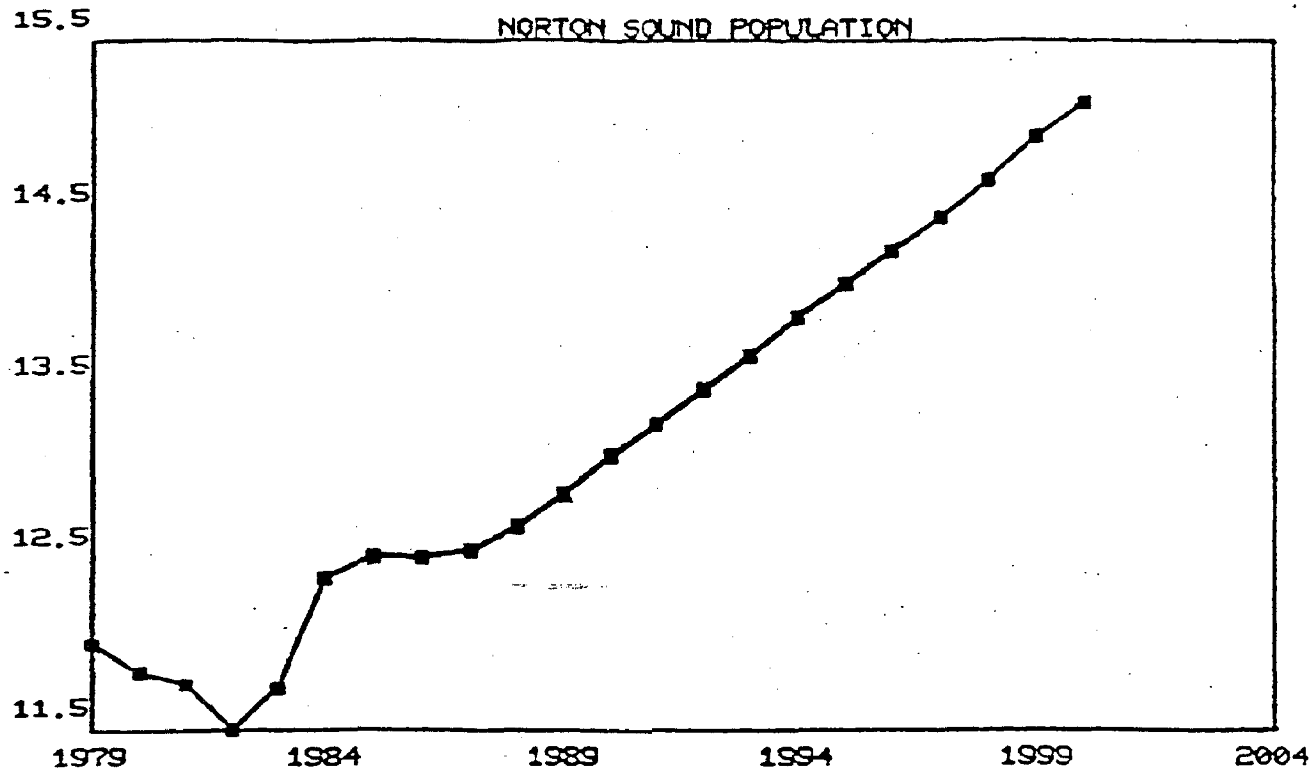
Finally, roads may present a physical barrier to animal migrations or movement. If roads are maintained during winter months, high steep berms of plowed snow can restrict the mobility that many animals require in order to forage successfully and survive. Similarly, snow fences may produce the same effect.

An increase in human population and human presence (Figures 13, 14, and 15) will significantly affect fish and game resources by expanding hunting and fishing pressure, and by elevating levels of harassment. Increased numbers of people hunting and fishing will mean that a greater number of animals will be harvested, yet the carrying capacity of a

Figure 13 -

NORTON SOUND POPULATION, 1979-2000
BASE CASE

(thousands of persons)



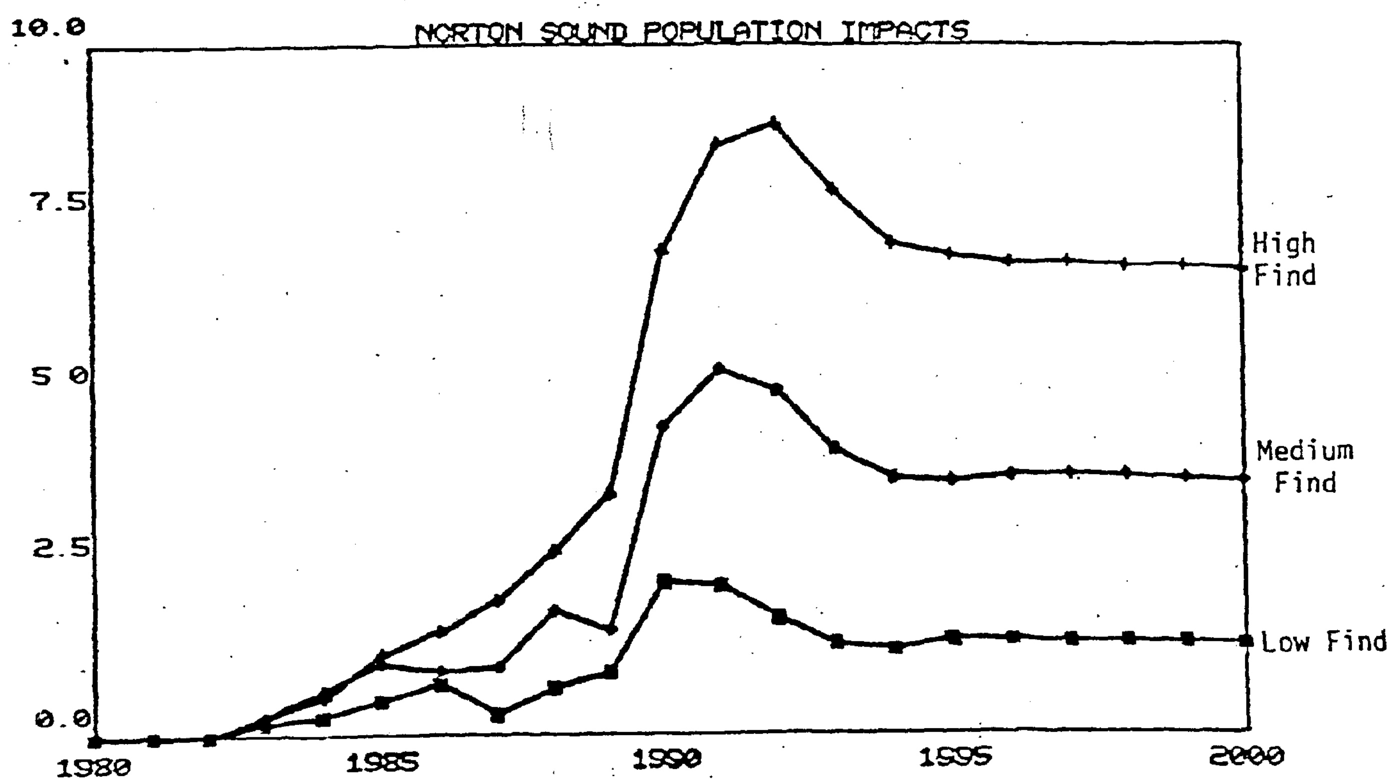
1979	12.016
1980	11.846
1981	11.776
1982	11.511
1983	11.752
1984	12.406
1985	12.525
1986	12.517
1987	12.556
1988	12.69
1989	12.886
1990	13.108
1991	13.292
1992	13.494
1993	13.682
1994	13.909
1995	14.105
1996	14.291
1997	14.491
1998	14.707
1999	14.949
2000	15.14

Source: MAP Model
Porter, 1980

Figure 14

NORTON SOUND POPULATION IMPACTS

(Thousands of Persons)



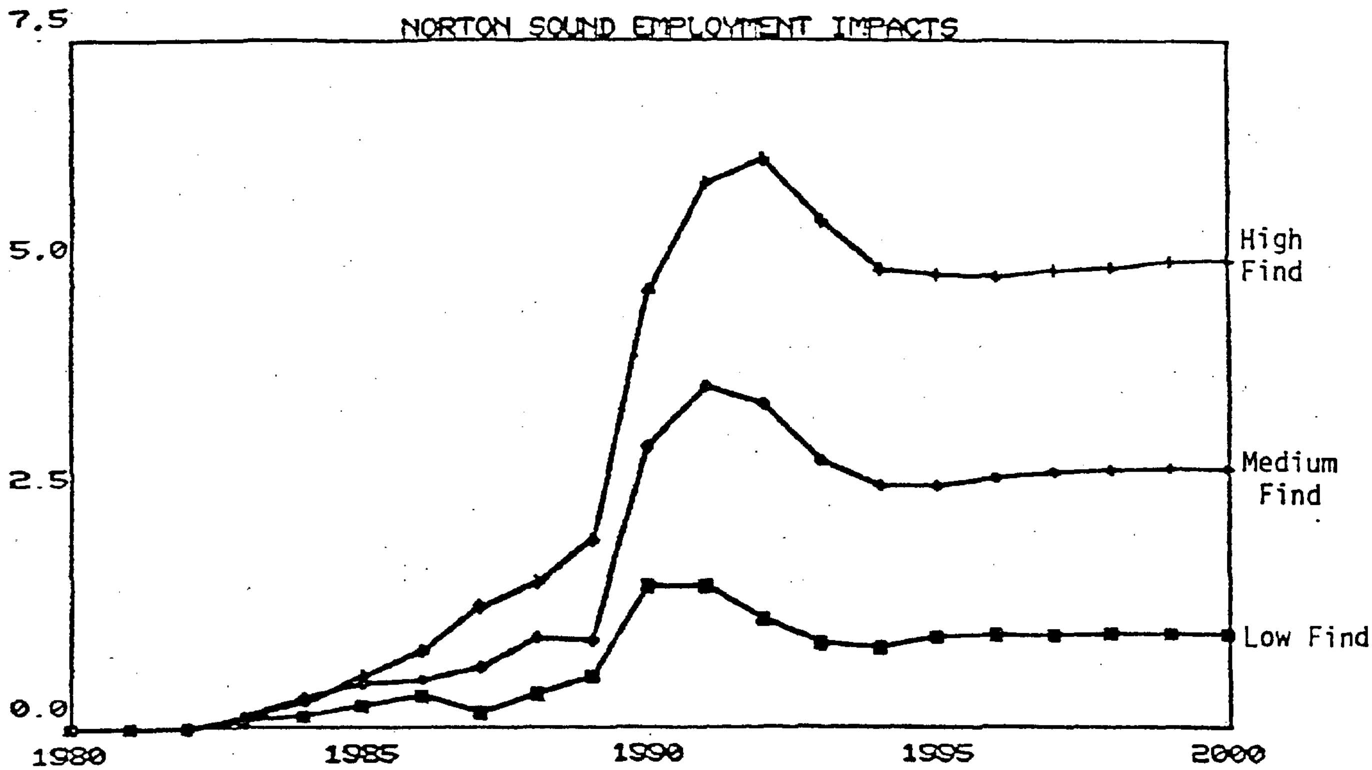
	EXPL	LOW	MOD	HIGH
1980	0.	0.	0.	0.
1981	0.	0.	0.	0.
1982	0.	0.	0.	0.
1983	0.095	0.189	0.289	0.283
1984	0.198	0.294	0.673	0.578
1985	0.108	0.524	1.048	1.206
1986	0.006	0.759	0.942	1.536
1987	0.004	0.308	0.998	2.
1988	0.003	0.7	1.832	2.708
1989	0.003	0.926	1.534	3.504
1990	0.002	2.265	4.473	7.015
1991	0.002	2.211	5.31	8.597
1992	0.002	1.718	5.018	8.874
1993	0.002	1.337	4.146	7.916
1994	0.002	1.262	3.729	7.14
1995	0.002	1.402	3.683	6.961
1996	0.002	1.392	3.756	6.847
1997	0.002	1.382	3.765	6.557
1998	0.002	1.371	3.761	6.816
1999	0.002	1.356	3.726	6.811
2000	0.002	1.341	3.688	6.747

Source: MAP Model
Porter, 1980

Figure 15

NORTON SOUND EMPLOYMENT IMPACTS

(Thousands of Persons)



	EXPL	LOW	MOD	HIGH
1980	0.	0.	0.	0.
1981	0.	0.	0.	0.
1982	0.	0.	0.	0.
1983	0.047	0.094	0.144	0.14
1984	0.104	0.152	0.343	0.295
1985	0.058	0.259	0.508	0.601
1986	0.001	0.377	0.542	0.877
1987	0.001	0.18	0.694	1.342
1988	0.	0.389	0.998	1.599
1989	0.	0.586	0.978	2.051
1990	0.	1.558	3.094	4.773
1991	0.	1.557	3.731	5.964
1992	0.	1.206	3.539	6.198
1993	0.	0.941	2.927	5.553
1994	0.	0.902	2.659	5.027
1995	0.	1.021	2.664	4.961
1996	0.	1.028	2.754	4.938
1997	0.	1.034	2.811	5.006
1998	0.	1.04	2.828	5.036
1999	0.	1.045	2.842	5.1
2000	0.	1.049	2.853	5.121

Source: MAP Model
Porter, 1980

habitat will limit the number of animals that can be taken. Harvests will need to be managed by altering 1) methods and means of taking game, 2) bag limits, 3) lengths and timing of seasons, and 4) limiting the number of hunters (by permit or punch card systems). Due to the extreme importance attributed to subsistence activities in this region (Ellanna, 1980) it might further be expected that some determination must be made concerning subsistence qualification.

Incidents of animal harassment will occur more frequently if human population levels increase. In most cases, low level harassment may constitute nothing more than stalking animals for nonconsumptive purposes such as viewing and picture taking. Such activities are unlikely to affect a large percentage of a species population and can be relatively harmless, unless an animal is extremely sensitive to human presence. Less amenable forms of harassment include chasing animals with motorized vehicles or aircraft, scaring animals with gunshots, handling young animals, or destroying a species critical habitat (e.g. nests, dens, spawning sites, etc.). Indiscriminate waste or garbage disposal may also be considered a form of indirect harassment since animals (particularly bears, foxes and birds) may come to rely on these sources for food. For reasons of safety or health, these animals must then be exterminated.

Harassment can produce the following effects on an animal: 1) a greatly elevated body metabolism which elevates the cost of living to the animal at the expense of its body growth, development, and reproduction, 2) physical exertion and temporary confusion, which may lead to death, illness, or reduced reproduction, and 3) avoidance or abandonment of areas in which animals experience harassment, leading to a reduction in the populations range, and ultimately a reduction of the population due to a loss of access to resources, increased predation, or increased cost of existence (Geist, 1975).

Sensitivity of Areas and Recommended Mitigative Measures

The adverse impacts of secondary development on fish, wildlife and habitat in the northern Bering Sea-Norton Sound region are a combination of disturbances that, for the most part, have been discussed previously within the Impact and Mitigation sections of this report. Through compliance with the mitigating measures already identified in those sections, many of the impacts associated with secondary development may be substantially minimized, or in some cases, completely eliminated. Additional mitigatory measures which have not been addressed include:

1. Site specific environmental studies should be conducted in any marine or terrestrial area likely to be impacted by secondary development operations. These studies should include comprehensive species inventories, food and habitat requirement surveys, and site specific mitigations.

2. Avoid siting and constructing road systems and facilities which parcel or separate a species critical habitat range.

3. During winter, roads should be plowed so that snow barriers are not left alongside which might serve to impede animal movements.

4. Salt should not be used on roads during winter in order to minimize wildlife attraction.

5. Off-road traffic should be restricted as much as possible to minimize damage to surrounding vegetation and to avoid undue harassment of animals living adjacent to the road system.

6. During summer months (June through September) or during periods when snow cover is inadequate to protect underlying vegetation, only low surface pressure vehicles should be allowed off of established roads or prepared foundations.

7. Public access on roads or airfields should be restricted where necessary to prevent increased human presence in critical fish and wildlife areas, and to maintain current sport and subsistence harvest levels in areas made accessible by lease activities or onshore development. Determinations of this nature should be made only after consultation with the Alaska Department of Fish and Game.

8. Utility corridors should be designed to accomodate additional loads to limit further construction in undisturbed areas.

9. Utility corridors should be consolidated with road systems as much as possible to minimize habitat disturbance.

10. Power and telephone lines should be constructed above ground to facilitate quick repair and to avoid extensive trenching in permafrost areas. Additionally, they should be constructed so

as to utilize existing land contours and natural barriers which will aid in minimizing bird/powerline collisions.

11. Implement environmental training programs to educate personnel as to the dangers of feeding, handling or harassing wildlife.

12. Limit the off-site and off-duty activities of workers to eliminate animal and human conflicts in sensitive areas.

13. Implement special game and fisheries management procedures or regulations which will serve to reduce competition between new workers and indigenous user groups.

14. Arrange for an exchange of dialogue between developers and surrounding communities. This may be accomplished by establishing meetings or forums on a regularly scheduled basis (bi-monthly/quarterly), in which representatives from the private and public sector may discuss problems and issues, new proposals, etc.

15. Edibles should be adequately stored from their initial arrival to their eventual disposal to avoid attracting animals. All edible garbage should be thoroughly incinerated.

16. A solid waste disposal program should be initiated which will, a) utilize materials that will not generate a large amount of solid waste in the form of packaging; b) maximize on-site

recycling of parts or materials, including specifically purchasing parts or materials amenable to rebuilding or recycling; and c) schedule support activities so that all freight carriers return with a load of solid waste.

17. Liquid waste disposal systems should, a) reduce the temperature of effluent discharge to minimize thermal erosion of subsurface permafrost; b) recycle water in a cascading system if certain processes do not require high water quality; and c) use a series of interconnected lagoons so that water for industrial use may be withdrawn from the last holding lagoon.

18. All liquid waste treatment lagoons should be lined and bermed with an impermiable material that will prevent leaching into the surrounding substrate.

19. Pesticides or defoliants should not be used for mosquito control or site maintainence unless it can be demonstrated that such chemicals will not accumulate in animal tissues, groundwater supplies, or soil sediments; and that such techniques will not preclude habitat utilization by other species.

20. Revegetation techniques should proceed immediately following termination of activity in an area not subject to additional operations.

21. All efforts should be made to restore an area to its original state. This would include restoration of vegetational composition, land contour, waterflow and soil characteristics.

22. Habitat improvement techniques should be implemented concurrent with development operations when it has been determined what species will be displaced, what their habitat requirements are, and if it is concluded that such practices will be beneficial. Examples of habitat improvement techniques would include the creation of additional denning, nesting, spawning or rearing sites; planting additional cover to compensate for that which is removed; seeding additional vegetation for forage in outlying areas, etc.

23. Whenever it is necessary to destroy important fish and wildlife habitat, mitigation should be required.

K

AIR POLLUTION

AIR POLLUTION

Sources and Biological Effects

Air emissions from oil and gas industry operations can be sources of air pollution. It is generally the case that the types of emissions produced depend on the function of the facility. The amount of pollution in the air is related to the types of products being produced, the kind of oil pollution control equipment being used, and the regional ambient (surrounding) air conditions. In Norton Sound, it is unlikely that oil refineries or petrochemical plants will be constructed; however, primary treatment facilities and liquified natural gas (LNG) plants are possible. Emmissions from these facilities include hydrocarbons, hydrogen sulfide, sulfur oxides, nitrogen oxides, carbon monoxide and particulate matter (NERBC, 1976). Vaporized hydrocarbons, such as LNG, may be emitted into the air at transfer points (i.e., marine terminals, LNG plants, fuel storage tanks, leaks from pipelines, valves, and seals) further adding to air problems (Clark and Terrell, 1978). An accident that released LNG to the atmosphere could result in a catastrophic explosion and fire (Clark, 1977). If petrochemical industries utilizing petroleum feedstocks should be constructed in Norton Sound and are located adjacent to production and processing facilities, air pollution may be compounded.

Construction of onshore facilities during the exploration, development, and production stages of oil development also contribute pollutants to the atmosphere. Two types of air pollution are usually generated, one type is from the exhaust of heavy machinery operating at the construction site and the second type is generated by dust from heavy machinery moving over exposed topsoil. Nitrogen oxide (NO2) is released by diesel-powered equipment, and carbon monoxide (CO) arises from gasoline-powered machinery (NERBC, 1976). The Alaska Department of Environmental Conservation anticipates that dust will be the major air quality problem at service bases in Alaska (ADCRA, 1978).

Plants and animals react to air pollutants such as hydrocarbons, sulfur dioxide, and nitrogen oxide in various ways. Some pollutants interfere with normal central nervous system functions while others are suspected of being carcinogenic (cancer-inducing) (NERBC, 1976). Polycyclic aromatic hydrocarbons, which are widely studied pollutants, are thought to cause lung cancer. Polycyclic aromatic hydrocarbons are found in crude petroleum and in the air surrounding refineries (Thomas, 1978). Sulphur dioxide has been shown to increase the frequency of respiratory irritation and disease in humans and animals; cause bleaching, growth suppression, and reduction in yield of plants; affect growth of lichens; and increase the acidity of rain and snow (NERBC, 1976; Saunders and Wood, 1973). Nitrogen oxide can cause eye and respiratory irritation in humans and animals, growth reduction in plants, and a discoloration (brown haze) of the atmosphere. Sulphur dioxide and nitrogen oxide are emitted by fossil fuel combustion engines, treatment plants, gas processing plants, and refineries (NERBC, 1976).

Studies in the British Isles, have shown that lichens are extremely sensitive to air pollution (especially sulphur dioxide). Changes in species diversity and abundance have reportedly occurred near urban areas, and lichen vegetation which has been subjected to air pollution can become considerably depleted (James, 1973). In eastern North America, the eastern white pine (Pinus strobus) is highly sensitive to pollutants such as sulphur dioxide, ozone, and nitrogen oxide. These pollutants reduce the growth in height and diameter of trees, and injure their foliage (Gerhold, 1977). The effects of air pollution on vegetation are apparent at the Collier Carbon and Chemical Corporation near Kenai (Dames & Moore, 1976a). This industry uses natural gas as a feedstock to produce liquid ammonia and urea, which are essential components for growing commerical crops. Spruce and birch trees adjacent to the plant, as well as in the rest of the industrial complex, are in poor condition. Dead or dying spruce trees and partially defoliated birch trees are more common is this area than those found greater distances from the complex. The emission of gaseous ammonia appears to be the responsible factor causing their poor condition (Dames & Moore, 1976a). In the northern Bering Sea and Norton Sound region, gaseous emissions of sulphur dioxide, nitrogen oxide, or polycyclic aromatic hydrocarbons will be localized around facilities or construction sites and are not likely to significantly affect wildlife.

Atmospheric pollution can also affect the ecosystem by causing a change in rainfall and snowfall patterns, lowered visibility, and local temperature changes (NERBC, 1976). Otts (1976) reported that moisture and heat discharged into the atmosphere by the large cooling towers of a power plant near Charleston, West Virginia contributed significantly to heavy snowfall downwind from the plant.

A major air pollutant during construction and operation phases in arctic and subarctic regions will be dust. Dust reduces visibility, and can increase the melt rate of snow resulting in vegetation changes and changes in drainage patterns. Accumulated dust may smother vegetation or increase turbidity and decrease light penetration in standing or flowing water.

The secondary development that accompanies the establishment of onshore oil and gas facilities may lead to the use of pesticides and herbicides. Contamination of the environment by pesticides (containing chlorinated hydrocarbons) or herbicides could have serious detrimental effects on marine birds, waterfowl, shorebirds, and raptors such as peregrine falcons and bald eagles. Accumulation of pesticide residues in these birds or their prey can eventually reduce reproductive success. There is usually a general decrease in fertility, a reduction in the viability of embryos and chicks, and eggshells become thinner and are easily crushed during incubation resulting in the loss of the embryo (ADF&G, undated; Nettleship, 1977). Peregrine falcons appear to be affected by eggshell thinning in all areas of their nearly global range, including areas in the Aleutians where they depend on marine food chains for survival (Ohlendorf, et al., 1978). Increased air traffic can also add to air pollution. Studies concerning the impacts on air quality resulting from the new north/south runway at Anchorage International Airport reveal that carbon monoxide, hydrocarbons, nitrogen oxide, and particulate matter (dust) were the most common pollutants associated with airport operations (Tigue and Carpenter, 1975).

Sensitivity of Areas and Recommended Mitigative Measures

Areas in the northern Bering Sea and Norton Sound were not ranked as having low, moderate or high sensitivity to the impacts of air pollution. The adverse impacts of air pollution on biological resources which can be anticipated from offshore oil development and associated secondary development in the northern Bering Sea and Norton Sound can be prevented, minimized, or ameliorated by complying with existing Environmental Protection Agency (EPA) and Alaska Department of Environmental Conservation (ADEC) Air Quality Standards.

REFERENCES

References for Impact and Mitigation Section

Alaska Beaufort Sea Oilspill Response Body (ABSORB). 1980. ABSORB oil spill contingency plan. Anchorage, Alaska.

Alaska Department of Community and Regional Affairs (ADCRA). 1978. Planning for offshore oil development. Gulf of Alaska OCS Handbook. Prepared by L.S. Kramer, V.C. Clark and G.J. Cannelos. 257 pp.

Alaska Department of Fish and Game (ADF&G). 1978. Resource report for Cook Inlet Sale No. 60. Marine and Coastal Habitat Management Project. October 1978. Anchorage, Alaska. 197 pp.

Alaska Department of Fish and Game (ADF&G). 1979a. Survey Inventory Progress Report - Moose, Game Management Unit 22 - Seward Peninsula. Game Division. Anchorage, Alaska. pp. 165-174.

Alaska Department of Fish and Game (ADF&G). 1979b. Annual Management Report Norton Sound-Kotzebue-Port Clarence. Commercial Fish Division. Anchorage, Alaska. 150 pp.

Alaska Department of Fish and Game (ADF&G). Undated. Alaska wildlife management plans for southcentral Alaska. Draft Proposal. 291 pp.

Alaska Oil and Gas Conservation Commission (AOGCC). 1981. Alaska drilling statistics. Anchorage, Alaska.

Albers, P.H. 1977. Effects of external applications of fuel oil in hatchability of mallard eggs. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Edited by D.A. Wolfe. Pergamon Press. pp. 158-163.

Allen, K.O. and J.W. Hardy. 1980. Impacts of navigational dredging on fish and wildlife: a literature review. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/07. 81 pp.

Alt, K.T. 1979. Inventory and cataloging of sport fish and sport fish waters of western Alaska. Federal Aid in Fish Restoration F-9-11. Sport Fish Division. Alaska Department of Fish and Game. Anchorage, Alaska. pp. 99-121.

American Petroleum Operators Association (APOA) and Environment Canada. 1976. Pollution from drilling wastes. Industry/Government Working Group "A". Vol. I. 123 pp.

American Society of Planning Officials (ASPO). 1978. Onshore impacts of outer continental shelf oil and gas development II. Workshop. Training Project for State and Local Officials. 175 pp.

Anchorage Times. 1980. "Polar bear dies, two ill after tests." Anchorage, Alaska.

Anderson, B.G. 1944. The toxicity thresholds of various substances found in industrial wastes as determined by the use of Daphnia magna. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission. 1978. Tech. Update 21. U.S. Department of Interior Geological Survey. p. A. 30.

Anderson, J.W. 1975. Laboratory studies on the effects of oil on marine organisms: an overview. In Accumulation and Turnover of Petroleum Hydrocarbons in Marine Organisms. R. Lee. 1977. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Edited by D.A. Wolfe. Pergamon Press. pp. 60-70.

Anderson, J.W. 1977. Responses to sublethal levels of petroleum hydrocarbons: are they sensitive indicators and do they correlate with tissue contamination. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Edited by D.A. Wolfe. Pergamon Press. pp. 95-114.

Anderson, J.W., J.M. Augenfeld, E.A. Crecelius and R. Riley. 1978. Research to determine the accumulation of organic constituents and heavy metals from petroleum-impacted sediments by marine detritivores of the Alaskan Outer Continental Shelf. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1978. Vol. VII - Effects. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 350-403.

Arctic Offshore. April 1979. Publication of the Alaska Oil and Gas Association.

Arctic Offshore. December 1980. Industry learns from Canadian, Alaskan offshore experience. Publication of the Alaska Oil and Gas Association. pp. 4-6.

Armstrong, H.W., K. Fucik, J.W. Anderson and J.M. Neff. 1979. Effects of oilfield brine effluent on sediments and benthic organisms in Trinity Bay, Texas. Marine Environ. Res. 2(1):55-69.

Atchison, G., B. Murphy, W. Bishop, A. McIntosh and R. Mays. 1977. Trace metal contamination of bluegill (Lepomis macrochirus) from two Indiana lakes. Transactions of the American Fisheries Society. 106(6):637-640.

Atema, J. 1977. The effects of oil on lobsters. Oceanus. 20(4):67-73.

Atlas, R. 1977. Assessment of potential interactions of micro-organisms and pollutants resulting from petroleum development on the outer continental shelf in the Beaufort Sea. In Annual Reports of Principal Investigators for the Year Ending March 1977. Vol. XI. Receptors: Microbiology. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 1-157.

Atlas, R.M. et al. 1980. Assessment of potential interactions of micro-organisms and pollutants resulting from petroleum development on the outer continental shelf of Alaska. Annual Reports of Principal Investigators for the Year Ending March 1980. Vol. II. Receptors: Microbiology, Ecological Processes. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 1-223.

Bailey, E.P. and G.H. Davenport. 1972. Die-off of common murres on the Alaska Peninsula and Unimak Island. The Condor. 74(2):215-219.

Barnard, W.D. 1978. Prediction and control of dredged material dispersion around dredging and open-water pipeline disposal operations. U.S. Army Eng. Waterways Exp. Stn., Vicksburg, Mississippi. Tech. Rep. DS-78-13. 113 pp.

Barnes, D. 1976. Development document for best technology available for the location, design, construction and capacity of cooling water intake structures for minimizing adverse environmental impact. Effluent Guidelines Division. Office of Water and Hazardous Materials. U.S. Environmental Protection Agency. Washington D.C. 263 pp.

Barry, T.W. and R. Spencer. 1976. Wildlife response to oil well drilling. Can. Wildl. Serv. Progress Note No. 67. Ottawa, Ontario. 15 pp.

Battelle Northwest. 1970. Review of Santa Barbara channel oil pollution incident. Wat. Poll. Cont. Res. Ser.

B.C. Research. 1975. Marine toxicity studies on drilling fluid wastes. Project No. 6114. Final report. Prepared for Working Group "A". APOA/Government Research Program on Drilling Fluid Wastes. Environment, Canada. B.C. Research. Vancouver, Canada. 17 pp.

Beak Consultants Ltd. 1974a. Disposal of waste drilling fluids in the Canadian Arctic. In Pollution from Drilling Wastes. Prepared for Working Group "A". APOA/Government Research Program on Drilling Fluid Wastes. Environment, Canada. B.C. Research. Vancouver, Canada. 123 pp.

Beak Consultants Ltd. 1974b. On-site drilling fluid monitoring and waste treatment testing. (Project C6014). In Pollution from Drilling Wastes. Prepared for Working Group "A". APOA/Government Research Program on Drilling Fluid Wastes. Environment, Canada. B.C. Research. Vancouver, Canada. 123 pp.

Becker, C.D., D.S. Trent, and M.J. Schneider. 1977. Predicting effects of cold shock: modeling the decline of a thermal plume. Battelle, Pacific Northwest Laboratories. Richland, Washington. NTIS No. PNL-2411. 26 pp.

Belikov, S.E. 1976. Behavior of the polar bear. Third International Conference on Bear Research and Management. International Union for the Conservation of Nature. In Polar Bear Reproductive Biology and Denning. J.W. Lentfer. Federal Aid in Wildlife Restoration Projects W-17-3 and W-17-4. Alaska Department of Fish and Game. Juneau, Alaska.

Benoit, D., E. Leonard, G. Christensen, and J. Fiandt. 1976. Toxic effects of cadmium on three generations of brook trout. Transactions of the American Fisheries Society. 105(4):550-560.

Biderman, J.O. and W.H. Drury. 1980. The effects of low levels of oil on aquatic birds. U.S. Fish and Wildlife Service, Biological Service Program. FWS/OBS-80/16. 5 pp.

Biesinger, K.E. and G.M. Christensen. 1972. Effects of various metals on survival, growth, reproduction and metabolism of Daphnia magna. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission. 1978. Tech. Update 21. U.S. Department of Interior Geological Survey. p. A. 33.

Bingham, C.R. 1978. Aquatic disposal field investigations, Duwamish waterway disposal site, Puget Sound, Washington; Appendix G: Benthic community structural changes resulting from dredged material disposal, Elliott Bay disposal site. U.S. Army Eng. Waterways Exp. Stn., Vicksburg, Mississippi. Tech. Rep. D-77-24. In Impacts of Navigational Dredging on Fish ~~and~~ Wildlife: A Literature Review. K.O. Allen and J.W. Hardy. 1970. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/07. 81 pp.

Blumer, M., G. Souza and J. Sass. 1970. Hydrocarbon pollution of edible shellfish by an oil spill. Marine Biology. 5(3):195-202.

Blumer, M., H.L. Sanders, J.F. Grassle and G.R. Hamson. 1971. A small oil spill. Environment. 13(2):2-12.

Blumer, M. and J. Sass. 1972. Oil pollution, persistence, and degradation of spilled fuel oil. Science. 176:1120-1122.

Boberschmidt, L., D.Carston, R. Hoberger and S. Saari. 1976. Considerations for the environmental impact assessment of small structures and related activities as applied to the Chicago District. U.S. Army Corps of Engineers. The Mitre Corp., McLean, Virginia. 2 vols.

Boesch, D. 1973. Biological effects of chronic oil pollution on coastal ecosystems. Background information for Ocean Affairs Board Workshop on Inputs, Fates and Effects of Petroleum in the Marine Environment. pp. 603-617.

Bonn, E. and B. Follis. 1967. Effects of hydrogen sulfide on channel catfish, Ictalurus punctatus. Transactions of the American Fisheries Society. 96(1):31-36.

Boreman, J. 1977. Impacts of power plant intake velocities on fish. Fish and Wildlife Resources and Electric Power Generation No. 1. Fish and Wildlife Service, Biological Services Program. FWS/OBS-76/20.1. 13 pp.

Bray, D.I., and G.T. Beauliew. 1973. A method for evaluation of time for passage of Atlantic salmon through an aboiteau. Paper for Canadian Hydraulics Conference, The University of Alberta. Edmonton, May 10 and 11. 13 pp.

Brett, J.R., M. Hollands, and D.F. Alderice. 1958. The effect of temperature on the cruising speed of young sockeye and coho salmon. Journ. Fish. Res. Board Canada. 15(4):587-605.

Breuer, J.P. 1962. An ecological survey of the Lower Laguna Madre of Texas. 1943-1959. Publ. Inst. Mar. Sci. Univ. Tex. 8:153-185. In Impacts of Navigational Dredging on Fish and Wildlife: A Literature Review. K.O. Allen and J.W. Hardy. 1980. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/07. 81 pp.

Brockson, R. and H. Bailey. 1973. Respiratory response of juvenile chinook salmon and striped bass exposed to benzene, a water-soluble component of crude oil. In Proceedings, Joint Conference on Prevention and Control of Oil Spills, pp. 783-792. American Petroleum Institute, Washington, D.C.

Brooks, J., B. Bernard and W. Sackett. 1976. Input of low-molecular-weight hydrocarbons from petroleum operations into the Gulf of Mexico. In Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. Edited by D.A. Wolfe. Pergamon Press. pp. 373-383.

Brower, W.A., H.W. Searby, J.L. Wise, H.F. Diaz and A.S. Prechtel. 1977. Climatic atlas of the outer continental shelf waters and coastal regions of Alaska - Vol. II - The Bering Sea. AEIDC. University of Alaska. Anchorage, Alaska.

Brown, J.M. 1968. The calculation of the acute toxicity of mixtures of poisons to rainbow trout. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission. 1978. Tech. Update 21. U.S. Department of Interior Geological Survey. p. A. 31.

Bureau of Land Management (BLM). 1976. Northern Gulf of Alaska final environmental impact statement. 4 volumes. Alaska Outer Continental Shelf Office. Anchorage, Alaska.

Bureau of Land Management (BLM). 1980. Final environmental statement - proposed five-year OCS oil and gas lease sale schedule - March 1980 - February 1985. U.S. Department of Interior. Anchorage, Alaska. 384 pp. and appendices.

Bureau of Land Management (BLM). Unpublished Data (a). Report from Lois Killewich. Drilling muds or fluids, and recommendation for research with respect to BLM decision-making. Anchorage, Alaska.

Bureau of Land Management (BLM). Unpublished Data (b). Inter-disciplinary session: impacts of potential OCS development on the Yukon Delta region. Edited by D.W. Menzel and F.F. Wright. Norton Sound Synthesis Meeting. Anchorage, Alaska.

Burger, C. and L. Swenson. 1977. Environmental surveillance of gravel removal on the trans-Alaska pipeline system with recommendations for future gravel mining. Special Report No. 13. Joint Federal/ State Fish and Wildlife Advisory Team. Anchorage, Alaska. 35 pp.

Burns, J.J. 1970. Remarks on the distribution and natural history of pagophilic pinnipeds in the Bering and Chukchi Seas. Journal of Mammology. 51(3):445-454.

Burns, J.J. 1980. Ice as marine mammal habitat in the Bering Sea. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. NOAA. U.S. Department of Commerce. 40 pp.

Burns, J.J., L.H. Shapiro and F.H. Fay. 1980. The relationships of marine mammal distributions, densities and activities to sea ice conditions. Environmental Assessment of the Alaskan Outer Continental Shelf. R.U. 248/249. Bureau of Land Management/OCS Office. Anchorage, Alaska. 183 pp.

Burrows, R.E. 1964. Effects of accumulated excretory products on hatchery-reared salmonoids. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission. 1978. Tech. Update 21. U.S. Department of Interior Geological Survey. p. A. 29.

Cacchione, D.A. and D.E. Drake. 1978. Sediment transport in Norton Sound. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1978. Vol. XII - Hazards. NOAA. U.S. Department of Commerce. Boulder, Colorado.

Cade, T.J. and C.W. White. 1976. Alaska's falcons: the issue of survival. The Living Wilderness. 39(132):35-47.

Calabrese, A. et al. 1973. The toxicity of heavy metals to embryos of the American oyster, Crassostrea virginica. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission. 1978. Tech. Update 21. U.S. Department of Interior Geological Survey. p. A. 33.

Caldwell, R.S., E.M. Calderone. and M.H. Mallon. 1977. Effects of a seawater-soluble fraction of Cook Inlet crude oil and it's major aromatic components on larval stages of the dungeness crab, Cancer magister Dana. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Edited by D.A. Wolfe. Pergamon Press. pp. 210-220.

Cameron, J.A., and R.L. Smith. 1980. Ultrastructural effects of crude oil on early life stages of Pacific herring. Transactions of the American Fisheries Society. 109:224-228.

Cameron, R.D. and K.R. Whitten. 1976. First interim report on the effects of the trans-Alaska pipeline on caribou movements. Special report No. 8. Joint Federal/State Fish and Wildlife Advisory Team. Anchorage, Alaska.

Cameron, R.D. and K.R. Whitten. 1977. Second interim report on the effects of the trans-Alaska pipeline on caribou movements. Special report No. 8. Joint Federal/State Fish and Wildlife Advisory Team. Anchorage, Alaska.

Cameron, R.D. and K.R. Whitten. 1978. Third interim report of the effects of the trans-Alaska pipeline on caribou movements. Special report No. 22. U.S. Department of the Interior. Anchorage, Alaska.

Capuzzo, J.M. and J.J. Sasner, Jr. 1977. The effect of chromium on filtration rates and metabolic activity of Mytilus edulis L. and Mya arenaria L. In Physiological Responses of Marine Biota to Pollutants. Edited by F.J. Vernberg, A. Calabrese, F.P. Thurberg, and W.B. Vernberg. Academic Press. New York. pp. 225-237.

Cardwell, R.D., C.E. Woelke, M.I. Carr and E.W. Sanborn. 1976. Sediment and elutriate toxicity to oyster larvae. In Proceedings of the Specialty Conference on Dredging and its Environmental Effects. Edited by P.A. Krenkel, J. Harrison and J. Clement Burdick III. American Society of Civil Engineers. New York. pp. 684-718.

Carlisle, J.G., C.H. Turner and E.E. Ebert. 1964. Artificial habitat in the marine environment. California Department of Fish and Game. Fisheries Bulletin. 124:73-74.

Carroll, A. Undated. Developer's handbook. State of Connecticut Department of Environmental Protection Coastal Area Management Program. 60 pp.

Carstea, D., L. Roberschmidt, R. Holberger, S. Saari and R. Strieter. 1976. Considerations for the environmental impact assessment of small structures and related activities as applied to the New Orleans District. In Biological Impacts of Minor Shoreline Structures on the Coastal Environment: State of the Art Review. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-77/51. 2 vol.

Center for Cold Ocean Resources Engineering (C-Core). 1980. An oil spill in pack ice. Memorial University of Newfoundland. St. Johns, Newfoundland. 231 pp.

Chapman, G. and D. Stevens. 1978. Acutely lethal levels of cadmium, copper and zinc to adult male coho salmon and steelhead. Transactions of the American Fisheries Society. 107(6):837-840.

Chapman, G. 1978. Toxicities of cadmium, copper, and zinc to four juvenile stages of chinook salmon and steelhead. Transactions of the American Fisheries Society. 107(6):841-847.

Chapman, G. Unpublished data available from National Water Quality Lab. Duluth, Minnesota. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission. 1978. Tech. Update 21. U.S. Department of Interior Geological Survey. p. A. 31.

Chesser, B.G. and W.H. McKenzie. 1975. Use of bioassay test in evaluating the toxicity of drilling fluid additives on Galveston Bay Shrimp. In Environmental Aspects of Chemical Use in Well-Drilling Operations. Conference Proceedings. Sponsored by Environmental Protection Agency: EPA 560/11-75-004. Houston, Texas. pp. 153-168.

Clark, J. and W. Brownell. 1973. Electric power plants in the coastal zone: environmental issues. American Littoral Society Special Publication No. 7. 130 pp.

Clark, J. 1977. Coastal ecosystem management; a technical manual for the conservation of coastal zone resources. John Wiley and Sons. New York. 928 pp.

Clark, J. and C. Terrell. 1978. Environmental planning for offshore oil and gas: Vol. III: Effects on Living Resources and Habitats. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-77/14. 220 pp.

Clay, C.H. 1961. Design of fishways and other fish facilities. In A Method for Evaluation of Time for Passage of Atlantic Salmon Through an Aboiteau. D.I. Bray and G.T. Beaulieu. 1973. Paper for Canadian Hydraulics Conference. The University of Alberta. Edmonton, May 10 and 11. 13 pp.

Coast Plains Center for Marine Development Service. 1973. Guidelines for the coastal zone. In Biological Impacts of Minor Shoreline Structures on the Coastal Environment: State of the Art Review. Vol I. E.L. Mulvihill, C.A. Francisco, J.B. Glad, K.B. Kaster and R.E. Wilson. 1980. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-77/51. 2 vol.

Conklin, P.J., D.G. Doughtie and K.R. Rao. 1980. Effects of barite and used drilling muds on crustaceans, with particular reference to the grass shrimp, Palaemonetes pugio. In Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. II. pp. 912-943.

Continental Shelf Associates. 1975. East Flower Garden Bank environmental survey. Lease OCS G-2759 for Mobil Oil Corporation. In Drilling Muds or Fluids, and Recommendations for Research with Respect to BLM Decision-Making. Bureau of Land Management. Unpublished report. Anchorage, Alaska.

Corner, E.D.S., A.J. Southward and E.C. Southward. 1968. Toxicity of oil spill removers (detergents) to marine life: an assessment using the intertidal barnacle Eliminus modestus. Marine Biology. 48:29.

Coventry, F.L., V.E. Shelford and L.F. Miller. 1935. The conditioning of a chloramine treated water supply for biological purposes. Ecology. 16(1):60-66.

Cox, J.C. and L.A. Schultz. 1980. The transport and behavior of spilled oil under ice. In Studies of the Behavior of Oil in Ice, Conducted by the Outer Continental Shelf Environmental Assessment Program. W.J. Stringer and G. Weller. Arctic Project Office. OCSEAP. University of Alaska. Fairbanks, Alaska. 17 pp.

Crippen, R.W. and S.L. Hood. 1980. Metal levels in sediment and benthos resulting from a drilling fluid discharge into the Beaufort Sea. In Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. I. pp. 636-669.

Cronin, L.E., G. Gunter and S.H. Hopkins. 1971. Effects of engineering activities on coastal ecology. Report to the Office of the Chief of Engineers. U.S. Army. 48 pp.

Dames and Moore. 1976a. Environmental impact report. Proposed Ammonial Area plant Expansion, Kenai, Alaska. For Collier Carbon and Chemical Corporation. 322 pp.

Dames and Moore. 1976. Oil spill trajectory analysis - Lower Cook Inlet, Alaska. In Lower Cook Inlet Final Environmental Statement, Vol. 2. Alaska Outer Continental Shelf Office. Anchorage. Alaska.

Dames and Moore. 1978. Drilling fluid dispersion and biological effects study for the Lower Cook Inlet C.O.S.T. Well. Atlantic Richfield Company. Anchorage, Alaska. 309 pp.

Dandy, J.W.T. 1967. The effects of chemical characteristics in the environment on the activity of aquatic organisms. Thesis. University of Toronto.

Dandy, J.W.T. 1972. Activity response to chlorine in the brook trout Salvelinus fontinalis (Mitchill). Canada Journal of Zoology. 50(4):405-410.

Danenberger, E.P. 1980. Outer continental shelf oil and gas blowouts. U.S. Geological Survey. Department of the Interior. Washington, D.C. np.

Darnell, R.M., W.E. Pequegnat, B.M. James, and B.J. Benson et al. 1976. Impacts of construction activities in wetlands of the United States. Environmental Protection Agency, Washington, D.C. EPA-600/3-76-045. In Impacts of Navigational Dredging on Fish and Wildlife: A Literature Review. K.O. Allen and J.W. Hardy. 1980. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/07. 81 pp.

Daugherty, F.M. 1950. Effects of some chemicals used in oil well drilling on marine animals. In Drilling Fluid Dispersion and Biological Effects Study for the Lower Cook Inlet C.O.S.T. well. Prepared by Dames and Moore. Anchorage, Alaska. 309 pp.

Deacutis, C.F. 1978. Effect of thermal shock on predator avoidance by larvae of two fish species. Trans. Am. Fish. Soc. 107(4):632-635.

DeGraeve, G.M., W.J. Blogoslawski, W.A. Brungs, J.A. Fava, B.J. Finlayson, T.P. Frost, T.M. Krischan, J.W. Meldrim, D.T. Michaud, R.E. Nakatani and G.L. Seegert. 1979. Chlorine. In A Review of the EPA Red Book: Quality Criteria for Water. Edited by R.V. Thurston, R.C. Russo, C.M. Felterolf, Jr., T.A. Edsall and Y.M. Barber, Jr. 1979. Water Quality Section. American Fisheries Society. Bethesda, Maryland. pp. 277-280.

Devries, A.L. 1977. The physiological effects of acute and chronic exposure to hydrocarbons on near-shore fishes of the Bering Sea. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1977. Vol. XII - Effects. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 1-22.

Dey, D.B. and D.M. Damkaer. 1977. Initial zooplankton investigations in Prince William Sound, Gulf of Alaska, and Lower Cook Inlet. Research Unit #425. Environmental Assessment of the Alaskan Continental Shelf, Annual Reports of Principal Investigators for the Year Ending March 1977. Vol. X. Receptors: Fish, Littoral, Benthos. NOAA. U.S. Department of Commerce. Boulder, Colorado. 138 pp.

Didiuk, A. and D.G. Wright. 1975. The effects of drilling waste on the survival and emergence of the chironomid "Chironomus tentans" (fabricius). 82nd Technical Report from the Research and Development Directorate Freshwater Institute. Winnipeg, Manitoba. 18 pp.

Dow, R.L. and J.W. Hurst, Jr. 1976. The ecological, chemical and histopathological evaluation of an oil spill site. Part I. Ecological studies. In The Effects of Petroleum Hydrocarbons on Marine Populations and Communities. A.D. Michael. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Edited by D.A. Wolfe. Pergamon Press. pp. 129-137.

Drury, W.H., J.O. Biderman, S. Hinckley and J.B. French, Jr. 1978. Ecological studies in the northern Bering Sea: birds of coastal habitats of the south shore of Seward Peninsula, Alaska. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1978. Vol. II. Receptors: Birds. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 510-613.

Dutta, L.K. 1976. A review of suction dredge monitoring in the Lower Fraiser River, 1971-1975. In Impacts of Navigational Dredging on Fish and Wildlife: A Literature Review. K.O. Allen and J.W. Hardy. 1980. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/07. 81 pp.

Ecomar Inc. 1978. Tanner Bank mud and cuttings study. Prepared for Shell Oil Company. Goleta, California. 495 pp.

EG&G Bionomics. 1976. Acute toxicity of seven materials to the calanoid copepod Acartia tonsa. Toxicity Test Report Submitted to Shell Oil Company. New Orleans, Louisiana. np.

Ehrhardt, M. 1972. Petroleum hydrocarbons in oysters from Galveston Bay. In Accumulation of Turnover of Petroleum Hydrocarbons in Marine Organisms. R. Lee. 1977. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Edited by D.A. Wolfe. Pergamon Press. pp. 60-70.

Ellanna, L.J. 1980. Bering-Norton petroleum development scenarios and sociocultural impacts analysis. Final Technical Report No. 54. Alaska OCS Socioeconomic Studies Program. BLM/OCS Office. Anchorage, Alaska. 455 pp.

Ender, R.L., S. Braund, S. Gorski, and G. Harrison. 1980. Bering-Norton petroleum development scenarios local socioeconomic systems analysis. Technical Report No. 53. Alaska OCS Socioeconomic Studies Program BLM/OCS Office. Anchorage, Alaska. 592 pp.

Environment Canada. 1975. Marine toxicity studies on drilling fluid wastes. Prepared for Working Group "A". APOA/ Government Research Program on Drilling Fluid Wastes. Edmonton, Alberta. 17 pp.

Environmental Protection Agency (EPA). 1974. Draft development document for effluent limitations guidelines and new source performance standards for the oil and gas extraction point source category. U.S. Env. Prot. Ag. Washington, D.C. np.

Esterly, C.W. 1975. The effect of a thermal effluent on the benthos of Thomas Hill Reservoir, Missouri. M.S. Thesis. Columbia School of Forestry, Fisheries, and Wildlife. University of Missouri. National Technical Information Service Publication No. PB-264 835. 63 pp.

Evans, C.D., W.J. Wilson, J.S. LaBelle, J.L. Wise, S. Cuccarese, D. Trudgen, R. Becker, A.L. Comiskey, J. Baldridge and S. Wilson. 1980. Environmental review of summer construction of gravel islands: Sag Delta No. 7 and No. 8. Stefansson Sound, Alaska. Prepared for Sohio Petroleum Company by Arctic Environmental Information and Data Center. University of Alaska. Anchorage, Alaska. 82 pp. and appendices.

Falk, M.R. and M.J. Lawrence. 1973. Seismic exploration; it's nature and effect on fish. Department of Environmental Fisheries and Marine Service. Fisheries Operations Directorate Central Region. Winnipeg, Canada. 51 pp.

Fay, F.H. 1961. The distribution of waterfowl to St. Lawrence Island, Alaska. In the Twelfth Annual Report of the Wildfowl Trust. Arctic Health Research Center. Public Health Service. U.S. Department of Health, Education and Welfare. Anchorage, Alaska. pp. 70-80.

Federal Energy Regulatory Commission. (FERC). 1978. Western LNG project draft environmental impact statement. Pacific Alaska LNG Associates (contractor). Vol. I. Construction and Operation of an LNG Liquification Terminal at Nikiski, Alaska. FERC/EIS-0002. 474 pp.

Federal Water Quality Administration (FWQA). 1970. Kodiak oil pollution incident February - March 1970. U.S. Department of the Interior.

Fletcher, J.L. 1979. Memo to CCEA members. College of Medicine. University of Tennessee.

Ford, J.K.B. 1977. White whale: offshore exploration acoustic study. Prepared for Imperial Oil Limited, Calgary, Canada. In The 1977 Whale Monitoring Program, Mackenzie Estuary, NWT. M.A. Fraker. For Imperial Oil Limited. F.F. Slaney and Co. Ltd. Vancouver, B.C. 53 pp.

Forshage, A. and N.E. Carter. 1973. Effects of gravel dredging on the Brazos River. In Gravel Removal Studies in Selected Arctic and Sub-Arctic Streams in Alaska. Woodward-Clyde Consultants. 1976. Preliminary Report prepared for U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-76/21. 127 pp.

Fossato, V. and W. Canzonier. 1976. Hydrocarbon uptake and loss by the mussel *Mytilus edulis*. Marine Biology. 36:243-250.

Fraker, M.A. 1977. The 1977 whale monitoring program, Mackenzie Estuary. NWT. For Imperial Oil Limited. F.F. Slaney and Co. Ltd. Vancouver, B.C. 53 pp.

Fraker, M.A., D.E. Sergeant and W. Hoek. 1978. Bowhead and white whales in the southern Beaufort Sea. Beaufort Sea Project. Technical Report No. 4. Victoria, B.C. 114 pp.

Fraker, M.A. 1979. Testimony on Beaufort Sea whales. Unpublished. Presented at hearings re: Beaufort Sea Lease Sale held at Fairbanks, Alaska; May 17, 1979. In Environmental Review of Summer Construction of Gravel Islands: Sag Delta No. 7 and No. 8 Stefansson Sound, Alaska. C.D. Evans, W.J. Wilson, J.C. LaBelle, J.L. Wise, S. Cuccarese, D.Trudgen, R. Becker, A.L. Comiskey J. Baldridge, and S. Wilson. 1980. Prepared for Sohio Petroleum Company by Arctic Environmental Information and Data Center. University of Alaska. Anchorage, Alaska. 82 pp. and appendices.

Frankenfeld, J.W. 1973. Factors governing the fate of oil at sea: variations in the amounts and types of dissolved or dispersed materials during the weathering process. In Impact of Oil on the Marine Environment - Reports and Studies No. 6. GESAMP. Food and Agriculture Organization of the United Nations. Rome, Italy. 250 pp.

Frost, K.J. 1979. Memorandum to J. Scott Grundy. Alaska Department of Fish and Game. February 15. 4 pp.

Fyfe, R.W. and R.R. Olendorff. 1976. Minimizing the dangers of nesting studies to raptors and other sensitive species. Canada Wildlife Service. Occasional Paper No. 23. 117 pp.

Gambrell, R.P., R.A. Khalid, W.H. Patrick, Jr. 1978. Disposal alternatives for contaminated dredged material as a management tool to minimize adverse environmental effects. U.S. Army Eng. Waterways Exp. Stn., Vicksburg, Mississippi. Tech. Rep. DS-78-8. 163 pp.

Geist, V. 1975. Harassment of large mammals and birds. Unpublished Report to the Berger Commission. In National Petroleum Reserve. Alaska Task Force, 1978. 62 pp.

Gentile, J. 1975. Semi-annual report. Environmental Protection Agency. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission. 1978. Tech. Update 21. U.S. Department of Interior Geological Survey. p. A. 33.

Geraci, J.R. and D.J. St. Aubin. 1980. Offshore petroleum resource development and marine mammals: a review and research recommendations. Marine Fisheries Review. November, 1980. 12 pp.

Gerber, R.P., E.S. Gilfillan, B.T. Page, D.S. Page, and J.B. Hotham. 1980. Short and long term effects of used drilling fluids on marine organisms. In Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. II. pp. 882-911.

Gerhold, J.D. 1977. Effects of air pollution on *Pinus strobus* L. and genetic resistence. A Literature Review. Corvallis Environmental Research Laboratory. Office of Research and Development. U.S. Environmental Protection Agency. Corvallis, Oregon. 44 pp.

Gettleson, D.A. and C.E. Laird. 1980. Benthic barium levels in the vicinity of six drill sites in the Gulf of Mexico. In Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. II. pp. 739-788.

Gilderhaus, P.A. 1966. Some effects of sublethal concentrations of sodium arsenite on bluegills and the aquatic environment. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission. 1978. Tech. Update 21. U.S. Department of Interior Geological Survey. p. A. 30.

Gilfillan, E.S. 1973. Effects of seawater extracts of crude oil on carbon budgets in two species of mussels. In Impact of Oil on the Marine Environment. Reports and Studies No. 6. GESAMP. IMCO/FAO/UNESCO/WMO/WHO/IAEA/UN. 250 pp.

Gilfillan, E.S. and J.H. Vandermeulen. 1978. Alterations in growth and physiology in chronically oiled shoft-shell clams, Mya arenaria, Chronically oiled with Bunker C from Chedabucto Bay, Nova Scotia, 1970-76. In Journal of the Fisheries Research Board of Canada. 35(5):630-636.

Gilliam, J. 1978. Impacts of oil and gas development and production on NPRA (Draft). U.S. Fish and Wildlife Service. Anchorage, Alaska. 98 pp.

Gulf of Alaska Cleanup Organization (GOACO). 1977. Oil spill cleanup manual. Anchorage, Alaska. 241 pp.

Gollop, M.A., R.A. Davis. 1974. Gas compressor noise simulator disturbance to snow geese, Komakuk Beach, Yukon Territory. September, 1972. In Disturbance to Birds by Gas Compressor Noise Simulators, Aircraft and Human Activity in the Mackenzie Valley and North Slope, 1972. Edited by W.W.H. Gunn and J.A. Livingston. Arctic Gas Biological Report Series. Vol. 14. Prepared by LGL Limited. Environmental Research Assoc. pp. 280-305.

Gollop, M.A., J.R. Goldsberry, and R.A. Davis. 1974a. Effects of gas compressor noise simulator disturbance to terrestrial breeding birds, Babbage River, Yukon Territory. June, 1972. In Disturbance to Birds by Gas Compressor Noise Simulators, Aircraft and Human Activity in the Mackenzie Valley and North Slope, 1972. Edited by W.W.H. Gunn and J.A. Livingston. Arctic Gas Biological Report Series. Vol. 14. Prepared by LGL Limited. Environmental Research Assoc. pp. 49-96.

Gollop, M.A., R.A. Davis, J.P. Prevett and B.E. Felske. 1974b. Disturbance studies of terrestrial breeding bird populations, Firth River, Yukon Territory. June, 1972. In Disturbance to Birds by Gas Compressor Noise Simulators, Aircraft and Human Activity in the Mackenzie Valley and North Slope, 1972. Edited by W.W.H. Gunn and J.A. Livingson. Arctic Gas Biological Report Series. Vol. 14. Prepared by LGL Limited. Environmental Research Assoc. pp. 97-152.

Gollop, M.A., J.E. Black, B.E. Felske, and R.A. Davis. 1974c. Disturbance studies of breeding black brant, common eiders, glaucous gulls, and Arctic terns, at Nunaluk spit and Phillips Bay, Yukon Territory. July, 1972. In Disturbance to Birds by Gas Compressor Noise Simulators, Aircraft and Human Activity in the Mackenzie Valley and North Slope, 1972. Edited by W.W.H. Gunn and J.A. Livingston. Arctic Gas Biological Report Series. Vol. 14. Prepared by LGL Limited. Environmental Research Assoc. pp. 153-201.

Gollop, M.A., J.R. Goldsberry, and R.A. Davis. 1974d. Aircraft disturbance to molting sea ducks, Herschel Island, Yukon Territory. August, 1972. In Disturbance to Birds by Gas Compressor Noise Simulators, Aircraft and Human Activity in the Mackenzie Valley and North Slope, 1972. Edited by W.W.H. Gunn and J.A. Livingston. Arctic Gas Biological Report Series. Vol. 14. Prepared by LGL Limited. Environmental Research Assoc. pp. 202-231.

Grahl-Nelson, O., S. Sundby, K. Westrheim, and S. Wilhelmsen. 1980. Petroleum hydrocarbons in sediment resulting from a production platform in the North Sea. In Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. I. pp. 541-561.

Grant, E.M. 1969. Kerosene taint in sea mullet. In IMCO/FAO/UNESCO/WMO/IAEA/UN. 197 pp. Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP). Rep. Stud. (6).250 pp.

Gray, R.H. 1977. Avoidance of thermal effluent by juvenile chinook salmon (Oncorhynchus tshawytscha) and its implications in waste heat management. Presentation and Publication in Proceedings of Waste Heat Management and Utilization Conference. Miami, Florida. May 9-11, 1977. Battelle, Pacific Northwest Laboratories. Richland, Washington. 15 pp.

Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP). 1977. Impact of oil on the marine environment. Reports and Studies, No. 6. IMCO/FAO/UNESCO/WMO/WHO/IAEA/UN. 250 pp.

Gusey, W.F. 1979. The fish and wildlife resources of the Norton Sound region. Environmental Affairs, Shell Oil Company. Houston, Texas.

Hampson, G.R. and E.T. Moul. 1978. No. 2 Fuel Oil Spill in Bourne, Massachusetts: immediate assessment of the effects on marine invertebrates and a 3-year study of growth and recovery of a salt marsh. Journal of the Fisheries Research Board of Canada. 35(5):731-744.

Hanley, P.T., W.W. Wade, G.S. Harrison, and D.F. Jones. 1980. Alaska OCS socioeconomic studies program Norton Basin OCS Lease Sale No. 57. Petroleum Development Scenarios Technical Report No. 49. Alaska OCS Office, Bureau of Land Management. Anchorage, Alaska.

Hanson, C.H. J.R. White and H.W. Li. 1977. Entrapment and impingement of fishes by power plant cooling-water intakes: an overview. Marine Fisheries Review. 39(10):7-17.

Hartung, R. 1965. Some effects of oiling on reproduction in ducks. Journal of Wildlife Management. 29:872-874.

Hartung, R. and G.S. Hunt. 1966. Toxicity of some oils to waterfowl. Journal of Wildlife Management. 30(3):564-570.

Hawkes, J. 1976. Morphological abnormalities produced by hydrocarbon exposure. EPA-NMFS Symposium on Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems, 10-12 Nov. 1976. Seattle, Washington. n.p.

Heiser, D.W.and E.L. Finn. 1970. Observations of juvenile chum and pink salmon in marina and bulkheaded areas. In Biological Impacts of Minor Shoreline Structures on the Coastal Environment: State of the Art Review. Vol. I. E.L. Mulvihill, C.A. Franscisco, J.B. Glad, K.B. Kaster and R.E. Wilson. 1980. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-77/51. 2 vol.

Herbert, D.W.M., J.S. Alabaster, M.C. Dart and R. Lloyd. 1961. The effect of china-clay wastes on trout streams. In A Literature Review. B. Land. 1974. Fisheries and Marine Service, Environment Canada. Technical Report No. 487. 33 pp.

Herbert, D.W.M. and J.C. Merkens. 1961. The effect of suspended mineral solids on the survival of trout. In A Literature Review. B. Land. 1974. Fisheries and Marine Service, Environment Canada. Technical Report No. 487. 33 pp.

Herbert, D.W.M. and A.C. Wakeford. 1962. The effect of calcium sulphate on the survival of rainbow trout. In A Literature Review. B. Land. 1974. Fisheries and Marine Service, Environment Canada. Technical Report No. 487. 33 pp.

Herbert, D.W.M. and J.M. Richards. 1963. The growth and survival of fish in some suspensions of solids of industrial origin. In A Literature Review. B. Land. 1974. Fisheries and Marine Service, Environment Canada. Technical Report No. 2187. 33 pp.

Herbert, D.W.M. and D.S. Shurben. 1965. The susceptibility of salmonoid fish to poisons under estuarine conditions - II. Ammonium Chloride. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission. Tech. Update 21. U.S. Department of Interior Geological Survey. p. A. 29.

Hesser, R., R. Hoopes, C.B. Weirich, J. Selcher, B. Hollender and R. Snyder. 1975. Chapter 2, the aquatic biota. In Clearcutting in Pennsylvania. The Pennsylvania State University, School of Forest Resources. University Park, Pennsylvania. pp. 9-20.

Holland, G.A., J.E. Lasater, E.D. Newmann and W.E. Eldridge. 1960. Toxic effects of organic pollutants on young salmon and trout. State of Washington Department of Fish. Res. Bull. No. 5. 260 pp.

Hoss, D.E., L.C. Coston and W.F. Hettler, Jr. 1971. Effects of increased temperature on post-larval and juvenile estuarine fish. Proceedings Conference of Southeast Association of Game and Fish Commissioners. 25:635-642.

Hoss, D.E., L.C. Coston, J.P. Baptist, and D.W. Engel. 1974a. Effects of temperature, copper and chlorine on fish during simulated entrainment in power-plant condenser cooling systems. In Environmental Effects of Cooling Systems at Nuclear Power Plants. 1974. IAEA Symposium on Hys. and Biol. Effects on the Environ. of Cooling Systems and Thermal Discharges at Nucl. Power Plants. pp. 519-527.

Hoss, D.E., Y.M. Barber, Jr., J.R.M. Kelso, G.R. Murnyak, J.B. Pearce and S.A. Spigarelli. 1979. Temperature. In A Review of the EPA Red Book: Quality Critera for Water. Edited by R.V. Thurston, R.C. Russo, and C.M. Felterolf, Jr. pp. 281-292.

Houghton, J.P., R.P. Britch, R.C. Miller, A.K. Runchal, and C.P. Falls. 1980. Drilling Fluid dispersion studies at the Lower Cook Inlet, Alaska, C.O.S.T. well. In Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. I. pp. 309-350.

Hoult, D.P., S. Wolfe, S. O'Dea and J.P. Patureau. 1975. Oil in the arctic. Office of Research and Development. U.S. Coast Guard. Dept. of Transportation. Washington, D.C. 217 pp.

Hrudey, S.E. 1979. Sources and characteristics of liquid process wastes from arctic offshore hydrocarbon exploration. Arctic. 32(1):1-21.

Hunt, G.L., Z. Eppley and W.H. Drury. 1980. Breeding distribution and reproductive biology of marine birds in the eastern Bering Sea. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce. Juneau, Alaska.

James, P. 1973. Introduction. In Air Pollution and Lichens. B. Ferry, M. Braddeley and D. Hawksworth. The Athlone Press. University of London. pp. 1-5.

Johnson, B.W. 1976. The effects of human disturbance on a population of harbor seals. Alaska Department of Fish and Game. Anchorage, Alaska. 10 pp.

Jolley, R.L., R.B. Cumming, W.W. Pitt, F.G. Taylor, J.E. Thompson and S.J. Hartmann. 1977. Ecological impact of chloro-organics produced by chlorination of cooling tower waters. Oak Ridge National Laboratory. Energy Research and Development Administration. To be published in Proceedings of the Symposium on Microbiology of Power Plant Effluents. University of Iowa. September 19-20. Iowa. 1977. 17 pp.

Joyce, M.R. 1980. Effects of gravel removal on terrestrial biota. In Gravel Removal Studies in Arctic and Sub-Arctic Floodplains in Alaska. Woodward-Clyde Consultants. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/08. pp. 215-271.

Kanter, R., D. Straughan and W.N. Jessee. 1971. Effects of exposure of oil on Mytilus californianus from different localities. In Prevention and Control of Oil Spills, American Petroleum Inst. pp. 485-488.

Kanter, R. 1974 Susceptibility of crude oil with respect to size, season and geographic location in Mytilus californianus (Bivalvia). Univ. of Southern California, Sea Grant Pub. USC-SG-4-74.

Kaplan, E.H., J.R. Welker, and M.G. Kraus. 1974. Some effects of dredging on populations of macrobenthic organisms. In Impacts of Navigational Dredging on Fish and Wildlife: A Literature Review. K.O. Allen and J.W. Hardy. 1980. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/07. 81 pp.

Karinen, J. and S. Rice. 1974. Effects of Prudhoe Bay crude oil on molting tanner crabs, Chionoecetes bairdi. Marine Fisheries Review. 36(7):31-37.

Katz, M. and R.A. Pierro. 1967. Estimates of the acute toxicity of ammonia - urea plant wastes to coho salmon, Oncorhynchus kisutch. Final report. Fisheries Research Institute, University of Washington, Seattle. 15 pp. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission. 1978. Tech. Update 21. U.S. Department of Interior Geological Survey. p. A. 29.

Kenyon, K.W. 1972. The effect of oil pollution on marine mammals. Environmental Protection Agency (WH-548). Washington, D.C. 9 pp.

King, R.G. 1974. The effects of heated water discharge on zooplankton in a 4,500 acre Missouri reservoir. M.S. Thesis. Columbia School of Forestry, Fisheries and Wildlife. University of Missouri. National Information Service. Publication No. PB-264 938. 78 pp.

Kinney, P.J. 1976. Oil slick movement in Alaskan waters. EPA-NMFS Symposium on Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems, 10-12 Nov. 1976. Seattle, Washington.

Knapp, W.E. 1978. Impacts of steam-electric power plants on fish and wildlife resources. Power Plant Project. U.S. Fish and Wildlife Service, Biological Services Program. 500+ pp.

Knieper, L. and D. Culley. 1975. The effects of crude oil on the palatability of marine crustaceans. Progressive Fish Culturist. 37(1):9-14.

Koons, C.B., C.D. McAuliffe, and F.T. Weiss. 1977. Environmental aspects of produced water from oil and gas extraction operations in offshore and coastal waters. Journal of Petroleum Technology. June 1977. pp. 723-729.

Kooyman, G.L., R.L. Gentry, and W.B. McAlister. 1976. Physiological impact of oil on pinnipeds. Final Report for Research Unit No. 71. OCSEAP. U.S. Department of Interior, Bureau of Land Management. 23 pp.

Kooyman, G.L., R.W. Davis and M.A. Castellini. 1977. Thermal conductance of immersed pinniped and sea otter pelts before and after oiling with Prudhoe Bay crude. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Edited by D.A. Wolfe. Pergamon Press. pp. 151-157.

Krebs, C.T. 1973. Qualitative observations of the marsh fidler (Ucca pugnax) populations in Wild Harbor Marsh following the September 1969 oil spill. NAS. Washington, D.C. Unpublished manuscript.

Krishnaswami, S.K. and E.E. Kupchanko. 1969. Relationship between odor of refinery wastewater and occurrence of "oily" taste-flavor in rainbow trout Salmo gairdneri. Journal of Water Pollution Control Federation. 41:184.

Kuhnhold, W.W. 1972. The influence of crude oils on fish. In Marine Pollution and Sea Life. Edited by M. Ruivo. Fishing News Ltd. London. 624 pp.

Land, B. 1974. The toxicity of drilling fluid components to aquatic biological systems - a literature review. Fisheries and Marine Service Technical Report No. 487. Environment Canada. Winnipeg, Manitoba. 33 pp.

LaRoche, G. 1973. Analytical approach in the evaluation of biological damage resulting from spilled oil. In Pollution Ecology of Estuarine Invertebrates - Clams and Snails (Mollusca). Edited by G.W. Hart, Jr., and S.L.H. Fuller. Academic Press. pp. 371-396.

Lawrence, M. and E. Scherer. 1974. Behavioral responses of whitefish and rainbow trout to drilling fluids. Environmental Canada Technical Report No. 502. 47 pp.

Lechner, J. 1970. Kodiak Naval Station fuel oil spill, Kodiak, Alaska. Alaska Department of Fish and Game Report. Kodiak, Alaska. 2 pp.

Lee, R.F. 1977. Accumulation and turnover of petroleum hydrocarbons in marine organisms. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Edited by D.A. Wolfe. Pergamon Press. pp. 60-70.

Lee, R.R., R. Sauerheber, and A.A. Benson. 1972. Petroleum hydrocarbons: uptake and discharge by the marine mussel Mytilus edulis. Science Magazine, July 1972. 177:334-346.

Lenarz, M. 1974. The reaction of Dall sheep to an FH-1100 helicopter. In Reaction of Some Mammals to Aircraft and Compressor Station Noise Disturbance. Edited by R.D. Jakimchuk. 1974. Arctic Gas Biological Report Series. Vol. 23. Prepared by Renewable Resources Consulting Services Ltd. 14 pp.

Lentfer, J.W. 1976. Polar bear reproductive biology and denning. Federal Aid in Wildlife Restoration Projects W-17-3 and W-17-4. Alaska Department of Fish and Game. Juneau, Alaska. 22 pp.

Levorsen, A.I. 1967. Geology of petroleum. W.H. Freeman and Company. San Francisco and London. 724 pp.

Levy, E.M. 1980. Oil pollution and seabirds: Atlantic Canada 1976-77 and some implications for northern environments. Marine Pollution Bulletin. 11(2):51-56.

LGL Limited. 1972. Aircraft disturbance to molting sea ducks, Herschel Island, Yukon Territory. Report prepared for Northern Engineering Service, Ltd. 31 pp.

Liss, R.G., F. Knox, D. Wayne, T.R. Gilbert and H.E. Edgerton. 1980. Availability of trace elements in drilling fluids to the marine environment. In Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. II. pp. 691-722.

Logan, W.J., J.B. Sprague and B.D. Hicks. 1973. Acute lethal toxicity to trout of drilling fluids and their constituent chemicals as used in the Northwest Territories. In Acute Toxicity of Petrochemical Drilling Fluids Components and Wastes to Fish. M.R. Falk and M.J. Lawrence. 1973. Canada, Dept. Environ., Fish. Mar. Serv., Op. Dir. Rep. No. CEN T-73-1. In A Literature Review. B. Land 1974. Fisheries and Marine Service, Environment Canada. Technical Report No. 487. 33 pp.

Logan, W.J., D.E. Thornton and S.L. Ross. 1975. Oil spill countermeasures for the southern Beaufort Sea. Beaufort Sea Project. Department of the Environment. Victoria, B.C. 126 pp.

Longley, W., R. Jackson and B. Snyder. 1978. Managing oil and gas activities in coastal environments. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-78/54. 220 pp.

Longwell, C.A. 1977. A genetic look at fish eggs and oil. Oceanus. 20(4):46-58.

Lunz, G.R. 1950. The effect of bleedwater and of water extracts of crude oil on the pumping rate of oysters. Texas A&M Research Foundation, Project 9. 107 pp. (mimeo). In A Review of Significant Papers on Effects of Oil Spills and Oilfield Brine Discharges on Marine Biotic Communities. J.G. Mackin. 1973. Texas A&M Research Foundation. Project 737. 86 pp.

Lynch, J.A., E.S. Corbett and R. Hoopes. 1977. Implications of forest management practices on the aquatic environment. Fisheries. 2(2):16-22.

McAuliffe, C.D. and L.L. Palmer. 1976. Environmental aspects of offshore disposal of drilling fluids and cuttings. Society of Petroleum Engineers of AIME. Paper No. SPE 5864. Longbeach, California. 6 pp.

McCain, B.B., H.O. Hodgins, W.D. Granlund, J.W. Hawkes, D.W. Brown, M.S. Myers and J.H. Vandermeulen. 1978. Bioavailability of crude oil from experimentally oiled sediments to English sole (Parophrys vetulus), and pathological consequences. J. Fish. Res. Board Can. 35:657-664.

McCain, B. 1978. The effects of Alaskan crude oil on flatfish and the prevalence of fish pathology in Alaskan marine waters. In Marine Biological Effects of OCS Petroleum Development. Edited by D.A. Wolfe. Environmental Research Laboratories, National Oceanic and Atmospheric Administration. pp. 54-71.

McCauley, J.A., D.R. Hancock and R.A. Parr. 1976. Maintenance dredging and four polychaete worms. In Proceedings of the Specialty Conference on Dredging and its Environmental Effects. Mobile, Alabama. Jan 26-28. Edited by P.A. Krenkel, J. Harrison and J.C. Burdick. American Society of Civil Engineers. New York. pp. 673-683.

McCourt, K.H., J.D. Feist, D. Doll and J.J. Russell. 1974. Disturbance studies of caribou and other mammals in the Yukon and Alaska, 1972. Arctic Gas Biological Report Series. Vol. 5. Prepared by Renewable Resources Consulting Services Ltd. 246 pp.

McCourt, K.H. and L. P. Horstman. 1974. The reaction of barren ground caribou to aircraft. In Reaction of Some Mammals to Aircraft and Compressor Station Noise Disturbance. Edited by R.D. Jakimchuk. 1974. Arctic Gas Biological Report Series. Vol. 23. Prepared by Renewable Resources Consulting Services Ltd. pp. 1-36.

McDermott and Company. Undated. The story of oil and gas. New Orleans, Louisiana. 28 pp.

McEwan, E.H. and A.C. Koelink. 1973. The heat production of oiled mallards and scaup. In Oil Pollution and Seabirds: Atlantic Canada 1976-77 and some Implications for Northern Environments. E.M. Levy. Marine Poll. Bull. Vol. II. pp. 51-56.

McKee, J.E., and H.W. Wolf. 1963. Water quality criteria. Resources Agency of California, State Water Resources Control Board Pub. No. 3-A. Sacramento, Calif. 548 pp.

McKim, J.M. 1974. Testimony in the matter of proposed toxic pollutant effluent standards for Aldren-Deildrin. FWPCA (307) Docket No. 1, Exhibit No. 4. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission. 1978. Tech. Update 21. U.S. Department of Interior Geological Survey. p. A. 32.

McKinley, W.R. and R.D. Webb. 1956. A proposed correction of migratory fish problems at box culverts. Washington Department of Fisheries. Fish. Res. Papers. 1(4):33-45.

McKnight, D.E. and C.E. Knoder. Undated. Resource development along coasts and on the ocean floor - potential conflicts with marine bird conservation. Alaska Department of Fish and Game. National Audubon Society. Lakewood, Co. 35 pp.

MacPhee, C. and F.J. Watts. 1976. Swimming performance of arctic grayling in highway culverts. Final report to U.S. Fish and Wildlife Service. Anchorage, Alaska. 41 pp.

Mackin, J.G. 1950. A report on three experiments to study the effect of oil bleedwater on oysters under aquarium conditions. Texas A&M Research Foundation, Project 9. In A Review of Significant Papers on Effects of Oil Spills and Oilfield Brine Discharges on Marine Biotic Communities. J.G. Mackin. 1973. Texas A&M Research Foundation. Project 737. 86 pp.

Mackin, J.G. and S.H. Hopkins. 1962. Studies on oyster mortality in relation to natural environments and to oil fields in Louisiana. 2402 Water Pollution Abstracts 1962. Publ. Inst. Mar. Sci. Univ. Tex. 7:1-131.

Mackin, J.G. 1971. A study of the effect of oil field brine effluents on biotic communities in Texas Bays. Texas A&M Res. Found., Project 735. 72 pp.

Mackin, J.G. 1973. A review of significant papers on effects of oil spills and oilfield brine discharges on marine biotic communities. Texas A&M Research Foundation. Project No. 737. Texas A&M University. 86 pp.

Maline, C.I. and R. Mlawski. 1978. Measurements of underwater acoustic noise in the Prudhoe Bay area, BBN, in April, 1978. For Exxon Production Research Co. In Memo to CCEA members. J.L. Fletcher. College of Medicine. University of Tennessee.

Malins, D.C., E.H. Gruger, H.O. Hodgins, N.L. Karrick and D.D. Weber. 1977. Sublethal effects of petroleum hydrocarbons and trace metals, including biotransformations, as reflected by morphological, chemical, physiological, pathological, and behavioral indices. In Quarterly Report for Contract No. R71 20819. OCSEAP Program. NOAA. U.S. Department of Commerce. Boulder, Colorado. 36 pp.

Malins, D.C., E.H. Gruger, Jr., H.O. Hodgins, N.L. Karrick and D.D. Weber. 1978. Sublethal effects of petroleum hydrocarbons and trace metals, including biotransformations, as reflected by morphological, chemical, physiological, pathological, and behavioral indices. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1978. Vol. VII - Effects. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 12-146.

Malins, D.C. 1980. Toxicity of oil in marine habitats. Paper presented to Norton Sound Synthesis Meeting, October 1980. Northwest and Alaska Fisheries Center, National Marine Fisheries Service. Seattle, Washington. 17 pp.

Manuwal, D.A. and D. Boersma. 1978. Dynamics of marine bird populations on the Barren Islands, Alaska. In Population Dynamics and Trophic Relationships of Marine Birds in the Gulf of Alaska and Southern Bering Sea. Edited by S.A. Hatch, D.R. Nysewander, A.R. DeGange, M.R. Petersen, P.A. Baird, K.D. Wohl, C.J. Lensink. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1978. Vol. III. Receptors: Birds. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 575-679.

Manzer, J.I., T. Ishida, A.E. Peterson and M.G. Hanavan. 1965. Salmon of the north Pacific Ocean--Part V. Offshore distribution of salmon. In Trans-shelf Movements of Pacific Salmon. R.R. Straty. 1980. National Marine Fisheries Service, Auke Bay Lab. Juneau, Alaska.

Marking, L.L. and T.D. Bills. In Press. Acute effects of silt and sand sedimentation of freshwater mussels. Proceedings of Symposium on Upper Mississippi River Bivalve Mollusks, 3 and 4 May, 1979. Performed for U.S. Army Engineer District. St. Paul, Minnesota. n.p.

Martin, S., P. Kauffman and P.E. Welander. 1978. A laboratory study of the dispersion of crude oil within sea ice grown in a wave field. In Proceedings of the 27th Alaska Science Conference. Edited by G.C. West. Fairbanks, Alaska pp. 261-287.

Martin, S. 1979. A field study of brine drainage and oil entrainment in first-year sea ice. Journal of Glaciology. 22(88):473-501.

Martin, S. 1980. Anticipated oil-ice interactions in the Bering Sea. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce.

Massengill. 1976. The Connecticut River ecological study. The impact of a nuclear power plant. Edited by D. Merriman and L.M. Thrope. Monograph No. 1. American Fisheries Society. Washington, D.C. 252 pp.

Mecklenburg, T., S. Rice and J. Karinen. 1976. Molting and survival of king crab (Paralithodes camtschatica) and coonstripe shrimp (Pandalus hypsinotus) larvae exposed to Cook Inlet crude oil water-soluble fraction. NOAA-EPA Symposium on Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms, 10-12 Nov. 1976. Seattle, Washington. 8 pp.

Meikle, K.M. 1978. Equipment development for arctic oilspill counter-measures. Spill Technology Newsletter. 3(3):163-169. May - June 1978.

Meldrim, J.W. and J.J. Gift. 1971. Temperature preference, avoidance and shock experiments with estuarine fishes. Ichthyological Associates Bulletin No. 7. 75 pp.

Menzel, R.W. and S.H. Hopkins. 1951. Report on experiments to test the effect of oil well brine or bleedwater on oysters at Lake Barre oil field. In A Review of Significant Papers on Effects of Oil Spills and Oilfield Brine Discharges on Marine Biotic Communities. J.G. Mackin. Texas A&M Research Foundation. Project 737. 86 pp.

Menzel, R.W. and S.H. Hopkins. 1953. Report on oyster experiments at Bay Ste, Elaine oil field. Texas A&M Research Foundation. Project 9.

Menzel, W. 1979. Clams and snails [Mollusca : Pelecypoda (except oysters) and Gastropoda]. In Pollution Ecology of Estuarine Invertebrates. Edited by C.W. Hart, Jr. and S.L.H. Fuller. Academic Press, Inc. pp 371-392.

Menzie, C.A., D. Maurer and W.A. Leatham. 1980. An Environmental monitoring study to assess the impact of drilling discharges in the Mid-Atlantic. Part IV. The Effects of Drilling Discharges on the Benthic Community. In Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. I. pp. 499-540.

Meyers, P. 1976. Effects of drilling operations on the hydrocarbon content of crustaceans. EPA-NMFS Symposium on Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems, 10-12 November. Seattle, Washington. 9 pp.

Michael, A.D. 1977. The effects of petroleum hydrocarbons on marine populations and communities. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Edited by D.A. Wolfe. Pergamon Press. pp. 129-137.

Miller, D.S., D.B. Peakall and W.B. Kinter. 1978. Ingestion of crude oil: sublethal effects in herring gull chicks. Science. 199(4326): 315-317.

Millikan, A., D. Penttila and D. Day. 1974. Puget Sound baitfish study, July 1, 1973-June 30, 1974. In Biological Impacts of Minor Shoreline Structures on the Coastal Environment: State of the Art Review. Vol I. E.L. Mulvihill, C.A. Francisco, J.B. Glad, K.B. Kaster and R.E. Wilson. 1980. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-77/51. 2 vol.

Mironov, O.G. 1969. Hydrocarbon pollution of the sea and it's influence on marine organisms. Helgolander Wiss. Meeresunters. Vol. 17. 335 pp.

Mix, M., R. Riley, K. King, S. Trenholm and R. Schaffer. 1976. Benzo(a) pyrene in economically important bivalve molluscs from Oregon estuaries. In Chemical Carcinogens in the Marine Environment. EPA Report Grant R80442710. 11 pp.

Moles, A., S.D. Rice and S. Korn. 1979. Sensitivity of Alaskan freshwater and anadromous fishes to Prudhoe Bay crude oil and benzene. Transactions of the American Fisheries Society. 108:408-414.

Moore, B., A. Beckett, and R.H. Weir. 1975. Acute Toxicity of drilling fluids to rainbow trout (Salmo gairdneri Richardson). In Pollution from Drilling Wastes. Arctic Petroleum Operators Association and Environment Canada. 1976. Industry/Government Working Group "A". Vol. I. 123 pp.

Moore, D. and L. Trent. 1971. Settling, growth and mortality of Crassostrea virginica in a natural marsh and a marsh altered by a housing development. In Biological Impacts of Minor Shoreline Structures on the Coastal Environment: State of the Art Review. Vol I. E.L. Mulvihill, C.A. Francisco, J.B. Glad, K.B. Kaster and R.E. Wilson. 1980. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-77/51. 2 vol.

Morehouse, T.A., R.A. Childers and L.E. Leask. 1978. Fish and wildlife protection in the planning and construction of the trans-Alaska oil pipeline. Institute of Social and Economic Research, University of Alaska, Anchorage. Performed for U.S. Fish and Wildlife Service. FWS/OBS-78/70. 131 pp.

Morrow, J. 1973. Effects of crude oil and some of its components on young coho and sockeye salmon. EPA-550/-3-73-018. 37 pp.

Morton, J.W. 1977. Ecological effects of dredging and dredge spoil disposal: a literature review. U.S. Fish and Wildlife Service. Department of Interior. Washington, D.C. Technical Papers of the U.S. Fish and Wildlife Service No. 94. 37 pp.

Moseley, H.R. 1980. Drilling fluids and cuttings disposal. In Symposium/ Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. I. pp. 43-52.

Moulton, L.L. 1980. Effects of gravel removal on aquatic biota. In Gravel Removal Studies in Arctic and Sub-Arctic Floodplains in Alaska. Woodward-Clyde Consultants. 1980a. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/08. pp. 141-214.

Mount, D.I. 1974. Chronic toxicity of methyl mercuric chloride to fathead minnows. Testimony in the matter of proposed toxic effluent standards for Aldrin-Dieldrin. FWPCA (307) Docket No. 1, Exhibit No. 4. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission. 1978. Tech. Update 21. U.S. Department of Interior Geological Survey. p. A. 32.

Muchmore, D. and D. Epel. 1973. The effects of chlorination of wastewater on fertilization in some marine invertebrates. Mar. Biol. 19:93-95.

Muench, R.D. 1980. Physical oceanography and circulation in Norton Sound. Summary of a verbal presentation at the Norton Sound synthesis meeting held in Anchorage. 28-30 October, 1980. 9 pp.

Mulvihill, E.L., C.A. Francisco, J.B. Glad, K.B. Kaster and R.E. Wilson. 1980. Biological impacts of minor shoreline structures on the coastal environment: state of the art review. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-77/51. 2 vol.

Murarka, I.P. 1977. A model for predicting fish impingment at cooling water intakes. Argonne National Laboratory. Argonne, Illinois. U.S. Department of Commerce. National Tech. Information Services. 53 pp.

NALCO Environmental Sciences. 1976. Physical and toxicity bioassay studies in Cook Inlet, Alaska during drilling operations. June-August 1976. Report to Union Oil Company of California. Project No. 55010, 7769 and 7773. Prepared by R.G. Johnson. 56 pp.

National Academy of Sciences (NAS). 1975. Petroleum in the marine environment. National Academy of Sciences Workshop. Washington, D.C. 107 pp.

National Oceanic and Atmospheric Administration (NOAA), U.S. Coast Guard (USCG), and Ministry for Greenland. 1979. USNS Potomac oil spill - Melville Bay, Greenland - August 5, 1977. U.S. Department of Commerce. Washington, D.C. n.p.

National Oceanic and Atmospheric Administration (NOAA) and Environmental Protection Agency (EPA). 1978. The Amoco Cadiz oil spill. A preliminary report. Edited by W.N. Hess. NOAA. Environmental Research Laboratories. Boulder, Colorado.

National Petroleum Reserve Alaska Task Force (NPRA). 1978. Draft public law 94-258 presidential study environmental analysis. 197 pp.

Neff, J.M., W.L. McCulloch, R.S. Carr, and K.A. Retzer. 1980. Comparative toxicity of four used offshore drilling muds to several species of marine animals from the Gulf of Mexico. In Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. II. pp. 866-881.

Nelson, D.W., S. Liu, and L.E. Sommers. 1980. Plant uptake of toxic metals present in drilling fluids. In Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. I. pp. 114-138.

Nelson-Smith, A. 1973. Oil pollution and marine ecology. Plenum Press. New York. 260 pp.

Nettleship, D.N. Undated. Seabird resources of eastern Canada: status, problems and prospects. In Canada's Threatened Species and Habitats. Proceedings of the Symposium on Canada's Threatened Species and Habitats Co-sponsored by Canadian Nature Federation and the World Wildlife Fund (Canada). Edited by T. Mosquin and C. Suchal. pp. 96-108.

New England River Basins Commission (NERBC). 1976. Onshore facilities related to offshore oil and gas development; factbook. 666 pp.

New England River Basins Commission (NERBC). 1978. Onshore facilities related to offshore oil and gas development. Tech. Update 21. U.S. Department of Interior, Geological Survey. pp. 49-95.

Nimmo, D., D. Lightner, and L. Bahner. 1977. Effects of cadmium on shrimp *Penaeus duoarum*, *Palaemonetes pugio* and *Palaemonetes vulgaris*. In Physiological Responses of Marine Biota to Pollutants. Edited by F.J. Vernberg, A. Calabrese, F. Thurberg, and W. Vernberg. Academic Press Inc. pp. 131-183.

Nisbett, I.C.T. 1977. In Coastal Ecosystem Management, a Technical Manual for the Conservation of Coastal Zone Resources. John Clark. John Wiley and Sons. New York. 928 pp.

Nitta, T. 1970. Marine Pollution in Japan. In Effect of Pollutants on Quality of Marine Products and Effects on Fishing. D.R. Idler. In Marine Pollution and Sea Life. Fishing News Ltd., Surrey England.

NORCOR Engineering and Research Ltd. 1975. The interaction of crude oil with Arctic Sea ice. Beaufort Sea Project. Department of the Environment. Victoria, B.C. 145 pp.

Northern Engineering Services Company, Ltd. and Aquatic Environments, Ltd. 1975. Reconnaissance of the Alyeska Pipeline - material source borrow methods and an evaluation of these methods with respect to aquatic habitats. In Gravel Removal Studies in Selected Arctic and Sub-Arctic Streams in Alaska. Woodward-Clyde Consultants. 1976. Preliminary Report prepared for U.S.Fish and Wildlife Service, Biological Services Program. FWS/OBS-76/21. 127 pp.

Northern Technical Services. 1980. Beaufort Sea drilling effluent disposal study for the Reindeer Island Stratigraphic test well. Prepared for the Sohio Alaska Petroleum Company. Anchorage, Alaska.

Northwest and Alaska Fisheries Center (NWAFC). 1979a. Adult steelhead runs in Columbia and Snake rivers impacted by low flows. Monthly Report, October. National Marine Fisheries Service. Seattle, Washington. pp. 13-14.

Northwest and Alaska Fisheries Center (NWAFC). 1979b. Juvenile English sole do not avoid oil contaminated sediments. Monthly report - November 1979. NOAA. NMFS. Seattle, Washington. pp. 24-25.

Northwest and Alaska Fisheries Center (NWAFC). 1980. Seawater temperature influences survival, external darkening and status of smoltification of steelhead. Monthly Report, June. National Marine Fisheries Service. Seattle, Washington. pp. 11-13.

Notini, M. 1978. Long-term effects of an oil spill on Fucus macrofauna in a small Baltic Bay. Journal of the Fisheries Research Board of Canada. 35(5):745-753.

O'Connor, J.M., L.A. Neumann and J.A. Sherk, Jr. 1976. Lethal effects of suspended sediments on estuarine fish. U.S. Department of Commerce. National Technical Information Service. University of Maryland. College Park, Maryland.

Odum, W.E. 1970. Insidious alteration of the estuarine environment. Transactions of the American Fisheries Society. 99(4):836-847.

Ohlendorf, H.M., R.W. Risebrough and R.Vermeer. 1978. Exposure of marine birds to environmental pollutants. U.S. Fish and Wildlife Service. Department of Interior. Wildlife Research Report No. 9. Washington, D.C. 41 pp.

Oliveira, L.P.H., de. 1924. Report of the Commissioner. In Water Quality Criteria. J.D. McKee and H.W. Wolf. 1973. Resources Agency of California, State Water Resources Control Board Pub. No. 3-A. Sacramento, Calif. p. 200.

Olson, P.A. 1958. Comparative toxicity of Cr (VI) and Cr (I-II) in salmon. In Water Quality Criteria. J.E. McKee and H.W. Wolf. 1963. Resources Agency of California, State Water Resources Control Board Pub. No. 3-A. Sacramento, Calif. p. 165.

Orcutt, D.R., B.R. Pulliam and A.Arp. 1968. Characteristics of steelhead trout redds in Idaho streams. In Gravel Removal Studies in Selected Arctic and Sub-Arctic Streams in Alaska. Woodward-Clyde Consultants. 1976. Preliminary Report prepared for U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-76/21. 127 pp.

Oregon State Game Commission and U.S. Public Health Service. 1955. Portland, Oregon. In Gravel Removal Studies in Selected Arctic and Sub-Arctic Streams in Alaska. Woodward-Clyde Consultants. 1976. Preliminary Report prepared for U.S. Fish and Wildlife Service, Biological Services Program. 127 pp.

Otts, R.E. 1976. Locally heavy snow downwind from cooling towers. NOAA. Technical Memorandum NWS ER-62. U.S. Department of Commerce. 4 pp.

Page, D.S., B.T. Page, J.R. Hotham, E.S. Gilfillan and R.P. Gerber. 1980. Bioavailability of toxic constituents of used drilling muds. In Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. II. pp. 984-996.

Patten, S.M., Jr. and L.R. Patten. 1977. Effects of petroleum exposure on hatching success and incubation behavior of glaucous-winged gulls (*Laurus glaucescens*) in the northeast Gulf of Alaska. Final Report for Research Unit No. 96. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1977. Vol. XII - Effects. NOAA. U.S. Department of Commerce. pp. 418-445.

Patten, S.M. and L.R. Patten. 1978. Effects of petroleum exposure on the breeding ecology of the Gulf of Alaska herring gull group (*Larus argentatus* x *Larus glaucescens*) and reproductive ecology of large gull in the northeast Gulf of Alaska. In Environmental Assessment of the Alaska Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1978. Vol. VII - Effects. NOAA. U.S. Department of Commerce. pp. 151-309.

Pavlov, D.S. and A.M. Pakhorukov. 1973. Biological basis of protecting fish from entry into water intake structures. In Pischchevaya Promyshlennost, 208 pp. (Translated by: S. Pearson, NMFS, NW Fisheries Center, 1974). In Draft Environmental Impact Statement, Prudhoe Bay Oil Field. Waterflood Project. U.S. Army Corps of Engineers, Alaska District. 1980. 2 vol.

Pearson, C.A., H.O. Mofjeld and R.B. Tripp. 1980. Tides of the eastern Bering Sea Shelf (draft). In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce

Pease, C.H. 1979. Eastern Bering Sea ice dynamics and thermodynamics. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce. n.p.

Peddicord, R. and V. McFarland. 1976. Effects of suspended dredged material on the commercial crab, *Cancer magister*. In Proceedings of the Specialty Conference on Dredging and its Environmental Effects. Mobile, Alabama. Jan. 26-28. Edited by P.A. Krenkel, J. Harrison and J.C. Burdick. American Society of Civil Engineers. New York. pp. 633-644.

Pequegnat, W.E., D.D. Smith, R.M. Darnell and B.J. Presley. 1978. An assessment of the potential impact of dredged material disposal in the open ocean. U.S. Army Eng. Waterways Exp. Stn., Vicksburg, Mississippi. Technical Report D-78-2. In Impacts of Navigational Dredging on Fish and Wildlife: A Literature Review. K.O. Allen and J.W. Hardy. 1980. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/07. 83 pp.

Percy, J.A. and T.C. Mullin. 1975. Effects of crude oils on Arctic marine invertebrates. Beaufort Sea Technical Report No. 11. Department of the Environment. Victoria, B.C.

Phillips, R.C. 1978. Seagrasses and the coastal marine environment. Oceanus. 21(3):28-40.

Pickering, Q.H. 1974. Chronic toxicity of nickel to the fathead minnow. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission, 1978. Tech. Update 21. U.S. Department of Interior Geological Survey. p. A. 33.

Pickering, Q.H., and C. Henderson. 1966. The acute toxicity of some heavy metals to different species of warm water fishes. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission. 1978. Tech. Update 21. U.S. Department of Interior Geological Survey. p. A. 31.

Porter, E.D. 1980. Bering-Norton petroleum development scenarios economic and demographic analysis. Alaska OCS Socioeconomic Studies Program. BLM/OCS Office. Anchorage, Alaska. 176 pp.

Portmann, J.E. 1972. Results of acute toxicity tests with marine organisms, using a standard method. In Marine Pollution and Sea Life. Food and Agriculture Organization (FAO) of the United Nations. pp. 212-217.

Prentice, E.F., and F.N. Ossiander. 1974. Fish diversion systems and biological investigation of horizontal traveling screen, Model VII. In Proceedings of the Second Workshop on Entrainment and Intake screening EPRI No. 74-049-005, Electric Power Research Institute.

Pringle, B.H. et al. 1968. Trace metal accumulation by estuarine molluscs. Jour. Sanit. Eng. Div., Proc. Am. Soc. Civil Eng. 94:455. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission. 1978. Tech. Update 21. U.S. Department of Interior Geological Survey. p. A. 31.

Pruitt, G., B. Grantham, and R. Pierce. 1977. Accumulation and elimination of pentachlorophenol by bluegill, *Lepomis macrochirus*. In Transactions of the American Fisheries Society. 106(5):462-465.

Quigley, E. 1977. Utility line siting and wetland preservation. In Wetland Ecology, Values, and Impacts. Edited by C.B. DeWitt and E. Soloway. pp. 108-115.

Ray, S.S., R.L. Snipes and D.A. Tomljanovich. 1976. A state-of-the-art report on intake technologies. Interagency Energy - Environment Research and Development Program Report. Tennessee Valley Authority and U.S. Environmental Protection Agency. AEPA Report No. EPA-600/7-76-020. 82 pp.

Read, A.D. and R.A. Blackman. 1980. Oily water discharges from offshore North Sea installations: a perspective. Marine Pollution Bulletin. 2(2):44-47.

Renfro, J.L., B. Schmidt-Nielson, D. Miller, D. Benos, and J. Allen. 1974. Methylmercury and inorganic mercury: Uptake distribution and effect on osmoregulatory mechanism in fishes. In Physiological Responses of Marine Biota to Pollutants. Edited by F.J. Vernberg. 1977. Academic Press. pp. 105-117.

Renzoni, A. 1975. Toxicity of three oils to bivalue gametes and larvae. In Pollution Ecology of Estuarine Invertebrates - Clams and Snails. Edited by C.W. Hart, Jr., and S.L.H. Fuller. Academic Press. pp. 371-396.

Reynolds, P.C. 1974. The effects of simulated compressor station sounds on Dall sheep using mineral licks in the Brooks Range, Alaska. In Reaction of Some Mammals to Aircraft and Compressor Station Noise Disturbance. Edited by R.D. Jakimchuk. 1974. Arctic Gas Biological Report Series. Vol. 23. Prepared by Renewable Resources Consulting Services Ltd. 130 pp.

Rice, S. 1973. Toxicity and avoidance tests with Prudhoe Bay oil and pink salmon fry. Proceedings of the Joint Conference on Prevention and Control of Oil Spills. API, EPA AND USGS. Washington, D.C. pp. 667-670.

Rice, J., D. Moles, and J. Short. 1975. The effect of Prudhoe Bay crude oil on survival and growth of eggs, alevins and fry of pink salmon (Oncorhynchus gorbuscha). In Proceedings of 1975 Conference on Prevention and Control of Oil Pollution. American Petroleum Institute, Environmental Protection Agency and U.S. Coast Guard, Washington, D.C.. pp. 503-507.

Rice, J. and J. Karinen. 1976. Acute and chronic toxicity uptake and depuration and sublethal metabolic response of Alaskan marine organisms to petroleum hydrocarbons. As reported in Reference Paper No. 6, Bureau of Land Management, Outer Continental Shelf Office, Anchorage, Alaska.

Rice, J., J. Short, C. Brodensen, T. Mecklenburg, D. Moles, C. Misch, D. Cheatham and J. Karinen. 1976. Acute toxicity and uptake-depuration studies with Cook Inlet crude oil, Prudhoe Bay crude oil, No. 2 fuel oil and several subarctic marine organisms. Northwest Fisheries Center. Auke Bay, Alaska. 87 pp.

Rice, S.D., R.E. Thomas and J.W. Short. 1977. Effect of petroleum hydrocarbons on breathing and coughing rates and hydrocarbon uptake depuration in pink salmon fry. In Physiological Responses of Marine Biota to Pollutants. Edited by F.J. Vernberg, A. Calabrese, F.P. Thurberg, and W.B. Vernberg. Academic Press pp. 259-274.

Rice, S.D., A. Moles, T.L. Taylor, and J.F. Karinen. 1979. Sensitivity of 39 Alaskan marine species to Cook Inlet crude oil and No. 2 fuel oil. In Proceedings of the 1979 Oil Spill Conference (Prevention, Behavior, Control, Cleanup). American Petroleum Institute, Environmental Protection Agency, and U.S. Coast Guard (sponsors). Los Angeles, California. pp. 549-554.

Riisgard, H.U. 1979. Danish marine oil pollution policy. Marine Pollution Bulletin. Sept. 1979. pp. 250-253.

Ronald, K., E. Johnson, M. Foster, and D. Vander Pol. 1970. The harp seal, Pagophilus groenlandicus (Erxleben, 1977), I. Methods of handling, molt, and diseases in captivity. In The Relationships of Marine Mammal Distributions, Densities, and Activities to Sea Ice Conditions. J.J. Burns, L.J. Shapiro and F.H. Fay. 1980. Final Report. Environmental Assessment of the Alaskan Continental Shelf. OCSEAP. NOAA. U.S. Department of Commerce. Boulder, Colorado. 172 pp.

Rosnegger, L. W. 1975. The movement of oil under sea ice. Beaufort Sea Project. Department of the Environment. Victoria, B.C. 81 pp.

Roubal, W., T. Collier and D. Malins. 1976. Significant levels of metabolites found in coho salmon exposed to aromatic hydrocarbons. NWAFC Monthly Report, Jan. 1976. National Marine Fisheries Service. 4 pp.

Roubal, W.T., T.K. Collier and D.C. Malins. 1977. Accumulation and metabolism of Carbon-14 labeled benzene, naphthalene, and anthracene by young coho salmon (Oncorhynchus kisutch). Arch. Environ. Contam. Toxicol. 5:513-529.

Roubal, W.T., S.I. Stranahan and D.C. Malins. 1978. The accumulation of low molecular weight aromatic hydrocarbons of crude oil by coho salmon (Oncorhynchus kisutch) and starry flounder (Platichthys stellatus). Arch. Environ. Contam. Toxicol. 7:237-249.

Rubenstein, N.I., R. Rigby and C.N. D'Asaro. 1980. Acute and sublethal effects of whole used drilling fluids on representative estuarine organisms. In Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. II. pp. 828-846.

Ruby, C.H. and M.O. Hayes. 1978. Oil spill vulnerability index, Copper River Delta. In Environmental Assessment of the Alaskan Continental Shelf. Quarterly Reports of Principle Investigators, October - December 1977. Vol. II. NOAA. U.S. Department of Commerce. Boulder, Colorado.

Rucker, R.R. and D.F. Amend. 1969. Absorption and retention of organic mercurials by rainbow trout and chinook and sockeye salmon. Prog. Fish Cult. 31:197-201.

Rundquist, L.A. 1980. Effects of gravel removal on river hydrology and hydraulics. In Gravel Removal Studies in Arctic and Sub-Arctic Floodplains in Alaska. Woodward-Clyde Consultants. 1980. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/08. pp. 67-138.

Salter, R. and R.A. Davis. 1974. Snow geese disturbance by aircraft on the north slope. September, 1972. In Disturbance to Birds by Gas Compressor Noise Simulators, Aircraft and Human Activity in the Mackenzie Valley and North Slope, 1972. Edited by W.W.H. Gunn and J.A. Livingston. Arctic Gas Biological Report Series. Vol. 14. Prepared by LGL Limited. Environmental Research Assoc. 305 pp.

Salter, R.E. 1979. Site utilization, activity budgets and disturbance responses of Atlantic walruses during terrestrial haul-out. Reprinted from Canadian Journal of Zoology. 57(6):169-1180.

Saucier, R.T., C.C. Calhoun, Jr., R.M. Engler, T.R. Patin, and H.K. Smith. 1978. Executive overview and detailed summary. Dredged Material Research Program. U.S. Army Eng. Waterways Exp. Stn., Environmental Laboratory, Vicksburg, Mississippi. 189 pp.

Saunders, J.W. and M.W. Smith. 1965. Changes in a stream population of trout associated with increased silt. Fisheries Research Board of Canada Biological Station. St. Andrews, N.B. Journal Fisheries Research Board of Canada. 22(2):395-404.

Saunders, P. and C. Wood. 1973. Sulphur dioxide in the environment: its production, dispersal and fate. In Air Pollution and Lichens. B. Ferry, M. Braddeley and D. Hawksworth. The Athlone Press. University of London. pp. 6-37.

Schmidt-Nielson, B. 1977. Effect of methyl mercury on osmoregulation, cellular volume, and ion regulation in winter flounder, Pseudopleuronectes americanus. In Physiological Responses of Marine Biota to Pollutants. Edited by F.J. Vernberg. 1977. Academic Press. pp. 105-117.

Schultz, L. 1980. The transport and behavior of oil spilled in and under sea ice. In Studies of the Behavior of Oil in Ice, Conducted by the Outer Continental Shelf Environmental Assessment Program. W.J. Stringer and G. Weller. NOAA. U.S. Department of Commerce. 17 pp.

Schweinsburg, R. 1974. Disturbance effects of aircraft on waterfowl on North Slope Lakes, June, 1972. In Disturbance to Birds by Gas Compressor Noise Simulators, Aircraft and Human Activity in the Mackenzie Valley and North Slope, 1972. Edited by W.W.H. Gunn and J.A. Livingston. Arctic Gas Biological Report Series. Vol. 14. Prepared by LGL Limited, Environmental Research Associates. pp. 1-47.

Schweinsburg, R.E., M.A. Gollop and R.A. Davis. 1974. Preliminary waterfowl disturbance studies, Mackenzie Valley, August 1972. In Disturbance to Birds by Gas Compressor Noise Simulators, Aircraft and Human Activity in the Mackenzie Valley and North Slope, 1972. Edited by W.W.H. Gunn and J.A. Livingston. Arctic Gas Biological Report Series. Vol. 14. Prepared by LGL Limited, Environmental Research Associates. pp. 232-257.

Selkregg, L.L. 1976. Alaska regional profiles: northwest region. Arctic Environmental Information and Data Center. University of Alaska. Anchorage, Alaska. 265 pp.

Shanks, L. 1978. Coastal systems and management options related to outer continental shelf (OCS) development. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-78/74. 13 pp.

Shanks, L.R. Undated. Small coastal structures - a review. U.S. Fish and Wildlife Service. 26 pp.

Shaw, D.R. 1976. The toxicity of some formation fluids and methods of rehabilitation subsequent to their spillage. Environmental Control, Sept. 1976. Montreal, Canada. pp. 37-41.

Sheen Technical Subcommittee. 1976. Environmental aspects of drilling muds and cuttings from oil and gas extraction operations in offshore and coastal waters. Offshore Operators Committee. 50 pp.

Sheridan R. 1967. Effects of gravel removal on a salmon spawning stream. In Gravel Removal Studies in Selected Arctic and Sub-Arctic Streams in Alaska. Woodward-Clyde Consultants. 1976. Preliminary Report prepared for U.S. Fish and Wildlife, Biological Services Program. FWS/OBS/-76/21. 127 pp.

Silvester, R. 1974. Coastal engineering, II: sedimentation, estuaries, tides, effluents and modeling. Elsevier Scientific Publishing Company. New York. 267 pp.

Smith, L.S., J.B. Saddler, R.D. Cardwell. A.J. Mearns, H.M. Miles and G.T. Sakagawa. 1969. Some physiological changes in juvenile Pacific salmon after capture and tagging. In Entrapment and Inpingement of Fishes by Power Plant Cooling Water Intakes: An Overview. C.H. Hanson, J.R. White and H.W. Li. 1977. Marine Fisheries Review. 39(10):7-17.

Smith, M. and M. Bonnett. 1976. Effects of crude oil exposure on king crab (Paralithodes camtschatica) gill morphology. In: EPA-NMFS Symposium on Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems, 10-12 Nov. 1976. Seattle, Wash.

Smith, T.G. and J.R. Geraci. 1975. Effect of contact and ingestion of crude oil on ringed seals. Beaufort Sea Technical Report No. 5. Beaufort Sea Project. Department of the Environment. Victoria, B.C. 66 pp.

Sowls, L.W. and J.C. Bartonek. 1974. Seabirds - Alaska's most neglected resource. Trans. N. Am. Wildl. Natural Resource Conference. 39:117-126.

Spaulding, W.M. Jr. and R.D. Ogden. 1968. Effects of surface mining on the fish and wildlife resources of the United States. In Gravel Removal Studies in Selected Arctic and Sub-Arctic Streams in Alaska. Woodward-Clyde Consultants. 1976. Preliminary Report prepared for U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-76/21. 127 pp.

Speakman, J.N. and P.A. Krenkel. 1972. Quantification of the effects of rate of temperature change on aquatic biota. In Predicting Effects of Cold Shock: Modeling the Decline of a Thermal Plume. C.D. Becker, D.S. Trent, and M.J. Schneider. 1977. Battelle, Pacific Northwest Laboratories. Richmond, Washington. NTIS No. PNL-2411. 26 pp.

Spears, R.W. 1971. An evaluation of the effects of oil field brine, and oil-removing compounds. AIME Environmental Quality Conference Proceedings. American Institute of Mining, Metallurgical, and Petroleum Engineers. Washington, D.C. pp. 199-216.

Spehar, R., E. Leonard, and D. Defoe. 1978. Chronic effects of cadmium and zinc mixtures on flagfish (Jordanella floridae). Transactions of the American Fisheries Society. 107(2):354-360.

Sprague, J. and D. Drury. 1969. Avoidance reactions of salmonoid fish to representative pollutants. In Advances in Water Pollution Research. Pergamon Press. pp. 169-179.

St. Amant, L.S. 1957. Investigation of oil taste in oysters caused by oil drilling operations. Louisiana Wildlife and Fisheries Commission. 7th Biennial Report, 1956-57. pp. 11-75.

St. Amant, L.S. 1971. Impacts of oil on the Gulf coast. Transactions of the 36th North American Wildlife and Natural Resources Conferences, Wildlife Management Institute. pp. 206-219.

Stainken, D.M. 1977. The accumulation and depuration of no. 2 fuel oil by the soft shell clam, Mya arenaria L. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Edited by D.A. Wolfe. Pergamon Press. pp. 313-322.

Stalmaster, M.V. and J.R. Newman. 1978. Behavioral Responses of wintering bald eagles to human activity. J. Wildlife Management. 42(3):506-513.

Steele, R.L. 1977. Effects of certain petroleum products on reproduction and growth of zygotes and juvenile stages of the alga Fucus edentatus De La Pyl. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Edited by D.A. Wolfe. Pergamon Press. pp. 138-142..

Stober, Q.J. and C.H. Hanson. 1974. Toxicity of chlorine and heat to pink (Oncorhynchus gorbuscha) and chinook salmon (Oncorhynchus tshawytscha). Trans. Amer. Fish Soc. No. 3. pp. 569-576.

Stockley. 1974. Salmon migrants and shellfish habitats in relation to marinas, breakwaters, bulkheads, and land fills in the Columbia River and coastal bays. Washington Department of Fisheries (Mimeo). 12 pp.

Stringer, W.J. and G. Weller. 1980. Studies of the behavior of oil in ice, conducted by the Outer Continental Shelf Environmental Assessment Program. Arctic Project Office, OCSEAP, University of Alaska. Fairbanks, Alaska. 17 pp.

Struhsaker, J.W., M.G. Eldridge and T. Echeverria. 1974. Effects of benzene (a water-soluble component of crude oil) on eggs and larvae of Pacific herring and northern anchovy. In Pollution and Physiology of Marine Organisms. Edited by F.J. Vernberg and W.B. Vernberg. Academic Press. pp. 253-285.

Swedmark, M., A. Granmo and S. Kollberg. 1973. Effects of oil dispersants and oil emulsions on marine animals. In Impact of Oil on the Marine Environment - Reports and Studies No. 6. GESAMP. Food and Agriculture Organization of the United Nations. Rome, Italy. 250 pp.

Szaro, R.C. and P.H. Albers. 1977. Effects of external applications of No. 2 fuel oil on common eider eggs. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Edited by D.A. Wolfe. Pergammon Press. pp. 164-167.

Tack, S.L. and J.G. Fisher. 1977. Performance of Arctic Grayling in a twenty foot section of Model "A" Alaska Steeppass fish ladder. Final Report to the Army Corps of Engineers, Alaska Division. 20 pp.

Taft, P. Hofmann, R.J. Eisle and T. Horst. 1976. An experimental approach to the design of systems for alleviating fish impingement at existing and proposed power plant intake structures. In Draft Environmental Impact Statement, Prudhoe Bay Oil Field. Waterflood Project. U.S. Army Corps of Engineers, Alaska District 1980. 2 vols.

Tagatz, M.E., J.M. Ivey, J.K. Lehman, and M. Tobia. 1980. Effects of drilling mud on development of experimental estuarine macrobenthic communities. In Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. II. pp. 847-865.

Takahashi, F.T. and J.S. Kitteredge. 1973. Sublethal effects of the water soluble component of oil: chemical communication in the marine environment. Publ. La. State Univ. pp. 259-264.

Taylor, J.L. and C.H. Saloman. 1967. Some effects of hydraulic dredging and coastal development in Boga Ciega Bay, Florida. In Impacts of Navigational Dredging on Fish and Wildlife: A Literature Review. K.O. Allen and J.W. Hardy. 1980. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/07. 81 pp.

Taylor, R.S. and M.C. James. 1928. Treatment for removal of chlorine from city water for use in aquaria. U.S. Bur. Fish. Doc. No. 1045. Rept. U.S. Comm. Fish. App. 7:322-327.

Taylor, T.L. and J.F. Karinen. 1977. Responses of the clam, Macoma balthica (Linnaeus), exposed to Prudhoe Bay crude oil as unmixed oil, water-soluble fraction, and oil-contaminated sediment in the laboratory. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Edited by D.A. Wolfe. Pergamon Press. pp. 229-237.

Teal, J. 1977. Food chain transfer of hydrocarbons. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Edited by D.A. Wolfe. Pergamon Press. pp. 17-77.

Teal, J.M., K. Burns, and J. Farrington. 1978. Analysis of aromatic hydrocarbons in intertidal sediments resulting from two spills of No. 2 fuel oil in Buzzards Bay, Massachusetts. Journal of the Fisheries Research Board of Canada. 35(5):510-520.

Tegelberg, H. 1964. Washington's razor clam fisheries in 1964. Washington State Department of Fisheries. Report No. 74. pp. 53-55.

Terry, J.M., R.G. Scoles, and D.M. Larson. 1980. Western Alaska and Bering-Norton petroleum development scenarios: Commercial fishing industry analysis. Technical Report No. 51. Alaska OCS Socioeconomic Studies Program. BLM/OCS Office. Anchorage, Alaska.

Tetra Tech. Inc. 1980. Port feasibility study, Nome, Alaska. Prepared for the City of Nome, Alaska. Report No. TC-3373. Anchorage, Alaska. 171 pp.

Thomas, D.B. 1978. Lung cancer and ambient air pollution. Environmental Law. 8:700-722.

Thomas, M. 1976. Long-term biological effects of Bunker C oil in the intertidal zone. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Edited by D.A. Wolfe. Pergamon Press. pp. 238-246.

Thomas R.E. and S.D. Rice. 1975. Effect of the water-soluble fraction of Prudhoe Bay crude oil on opercular rates of pink salmon, Oncorhynchus gorbuscha fry. J. Fish. Res. Board Can. Vol. 32. 12 pp.

Thompson, J.H. and T.J. Bright. 1980. Effects of an offshore drilling fluid on selected corals. In Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. II. pp. 1044-1078.

Thurston, R.V., R.C. Russo, C.M. Fetterolf, Jr., T.A. Edsall, and Y.M. Barber Jr. 1979. A review of the EPA Red Book: quality criteria for water. Water Quality Section, American Fisheries Society. Bethesda, Maryland. pp. 277-280.

Tigue, J. and L. Carpenter. 1975. Air quality impact analysis of a proposed north/south runway at Anchorage International Airport. Systems Research and Development Service. Federal Aviation Administration. U.S. Department of Transportation. Report No. FAA-RD-75-179. 50 pp.

Tomljanovich, D.A., J.H. Heuer, and C.W. Viogtlander. 1977. Investigations on the protection of fish larvae at water intakes using fine mesh screening. In Draft Environmental Impact Statement, Prudhoe Bay Oil Field. Waterflood Project. U.S. Army Corps of Engineers, Alaska District 1980.

Tornberg, L.D., E.D. Thielk, R.E. Nakatani, R.C. Miller and S.O. Hillman. 1980. Toxicity of drilling fluids to marine organisms in the Beaufort Sea, Alaska. In Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Vol. II. pp. 997-1016.

Trasky, L., L. Flagg, and D.C. Burbank. 1977. Environmental studies of Kachemak Bay and lower Cook Inlet. Vol. I. Alaska Department of Fish and Game. Marine/Coastal Habitat Management. 124 pp.

Trasky, L.L. 1977. Memo to K. Middleton. Proposed studies to assess environmental impacts of El Paso's proposed Gravina Point LNG plant. January 27.

Tsai, C. 1970. Changes in fish populations and migration in relation to increased sewage pollution in Little Patuxent River, Maryland. Ches. Sci. 11(1):34-41.

Tsai, C. 1973. Water quality and fish life below sewage outfalls. Trans. Amer. Fish. Soc. 102(2):281-292.

Tsai, C. 1975. Effects of sewage treatment plant effluent on fish: a review of the literature. CRC publication No. 36. 229 pp.

U.S. Army Corps of Engineers, Alaska District. 1980. Draft environmental impact statement, Prudhoe Bay oil field. Waterflood project. 2 Vol. 874 pp.

U.S. Army Corps of Engineers, Buffalo District. 1975a. Cooperative beach erosion project at Presque Isle Peninsula, Erie, PA. In Biological Impacts of Minor Shoreline Structures on the Coastal Environment: State of the Art Review. E.L. Mulvihill, C.A. Francisco J.B. Glad, K.B.Kaster and R.E. Wilson. 1980. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-77/51. 2 vol.

U.S. Army Corps of Engineers, Portland District. 1973. Study of hopper dredging coastal harbor entrance and Columbia River estuary bars. States of Oregon and Washington. In Impacts of Navigational Dredging on Fish and Wildlife: A Literature Review. K.O. Allen and J.W. Hardy. 1980. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/07. 81 pp.

U.S. Army Corps of Engineers, Seattle District. 1971. Everett Harbor, Washington, training dike and breakwater. Final EIS. U.S. Army Corps of Engineers, Seattle Washington. 10 pp.

U.S. Army Corps of Engineers, St. Paul District. 1974. Final environmental impact statement -- operation and maintenance, 9-foot channel, Upper Mississippi River, head of navigation to Guttenburg, Iowa. (Unpublished). In Impacts of Navigational Dredging on Fish and Wildlife: A Literature Review. K.O. Allen and J.W. Hardy. 1980. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/07. 81 pp.

U.S. Coast Guard (USCG). 1975. Comparison of ecological impacts of postulated oil spills at selected Alaskan locations. Final Report. Vol. I. Department of Transportation. Washington, D.C. np.

U.S. Coast Guard (USCG). 1978. Captain of the Port, western Alaska; pollution response plan. Anchorage, Alaska.

U.S. Coast Pilot-9 (USCP). 1979. Pacific and Arctic Coasts Alaska: Cape Spencer to Beaufort Sea. NOAA. U.S. Department of Commerce. Washington D.C. 354 pp.

U.S. Department of the Interior (USDI). 1976. Final environmental statement. Proposed 1976 Outer Continental Shelf Oil and Gas Lease Sale - Lower Cook Inlet. Bureau of Land Management. Vol. I. 1042 pp.

U.S. Environmental Protection Agency (USEPA). 1976. Development document for best technology available for the location, design, construction and capacity of cooling water intake structures for minimizing adverse environmental impact. In Draft Environmental Impact Statement, Prudhoe Bay Oil Field. Waterflood Project. U.S. Army Corps of Engineers, Alaska District, 1980. 2 vol.

U.S. Geological Survey (USGS). 1979. An environmental evaluation of potential petroleum development on the National Petroleum Reserve in Alaska. 238 pp.

U.S. Geological Survey (USGS). 1981. Mud additives information for Norton Sound Cost well No. 1. Letter from Jeff Walker (USGS) to Mark Kuwada (ADF&G) 3/18/81. 6 pp.

Uzuner, M.S., F.B. Weiskopf, J.C. Cox and L.A. Schultz. 1979. Transport of oil under smooth ice. Corvallis Env. Research Lab. U.S. Env. Protect. Agency. Corvallis, Oregon. 48 pp.

Vanderhorst, J., C. Gibson and L. Moore. 1976. Toxicity of No. 2 fuel oil to coonstripe shrimp. Marine Pollution Bulletin. Vol. 7. No. 6. n.p.

Varanasi, U. 1978. Biological fate of metals in fish. In Marine Biological Effects of OCS Petroleum Development. Edited by D.A. Wolfe. National Oceanic and Atmospheric Administration, Environmental Research Laboratories. 324 pp.

Varanasi, U. and D. Malins. 1977. Metabolism of petroleum hydrocarbons: accumulation and biotransformation in marine organisms. In Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms. Edited by D.C. Malins. Academic Press. Vol II. pp. 175-270.

Webb, W.E. and O.E. Casey. 1961. The effects of Placer mining (dredging) on a trout stream. Job Completion Report. In Gravel Removal Studies in Selected Arctic and Sub-Arctic Streams in Alaska. Woodward-Clyde Consultants. 1976. Preliminary Report prepared for U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-76/21. 127 pp.

Wechsler, B.A., and D.R. Cogley. 1977. A laboratory study of the turbidity generation potential of sediments to be dredged. Abcor, Inc., Wilmington, Massachusetts. In Impacts of Navigational Dredging on Fish and Wildlife: A Literature Review. K.O. Allen and J.W. Hardy. 1980. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/07. 81 pp.

Weir, R.H., W.H. Lake, and B.T. Thackeray. 1974. Acute toxicity of ten selected arctic drilling sumps to rainbow trout, Salmo gairdneri. (Richardson). In Pollution from Drilling Wastes. Arctic Petroleum Operators Association and Environment Canada. Industry/ Government Working Group "A". Vol. I. 123 pp.

Whitman, J. 1975. Center for natural areas spill report; date 09/27/75. In Impact of Oil on the Marine Environment. IMCO/FAO/UNESCO/ WMO/WHO/IAEA/UN. Reports and Studies, No. 6. 250 pp.

Wiens, J.A., G. Ford, D. Heinemann and C. Fieber. 1978. Simulation modeling of marine bird population energetics, food consumption and sensitivity to perturbation. In Breeding Distribution and Reproductive Biology of Marine Birds in the Eastern Bering Sea. G.L. Hunt Jr., Z. Eppley, and W.H. Drury. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce. Juneau, Alaska.

Williams, A.B. and T.W. Duke. 1979. Crabs (Arthropoda: Crustacea: Decapoda: Brachyura) In Pollution Ecology of Estuarine Invertebrates. Academic Press. pp. 171-233.

Wilson, K. 1976. Effects of oil dispersants on the developing embryos of marine fish. Marine Biology. 35:259-268.

Wilson, W.J., E.H. Buck, G.F. Player and L.W. Dreyer. 1977. Winter water availability and use conflicts as related to fish and wildlife in Arctic Alaska -- a synthesis of information. Arctic Environmental Information and Data Center. University of Alaska. Anchorage, Alaska. Performed for U.S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-77/06. 222 pp. and maps.

Wise, J.L. and H.W. Searby. 1977. Selected topics in marine and coastal climatology. In Climatic Atlas of the Outer Continental Shelf Waters and Coastal Regions of Alaska. Vol. II. The Bering Sea. W.A. Brower, H.F. Diaz, A.S. Prechtel, H.W. Searby, J.W. Wise. 1977. Alaska Environmental Information and Data Center. University of Alaska. Anchorage, Alaska. 442 pp.

Wobeser, G.A. 1973. Aquatic mercury pollution: studies of its occurrence and pathologic effects on fish and mink. Thesis: Department of Vet. pathology, Univ. of Saskatchewan, Saskatoon, Canada. In Onshore Facilities Related to Offshore Oil and Gas Development. New England River Basins Commission. 1978. Tech. Update 21. U.S. Department of Interior Geological Servey. p. A. 32.

Wobeser, G. 1975. Prolonged oral administration of methyl mercury chloride to rainbow trout (Salmo gairdneri) fingerlings. Journal of the Fisheries Research Board of Canada. 32(11):2015-2023.

Woodward-Clyde Consultants. 1976. Gravel removal studies in selected arctic and sub-arctic streams in Alaska. Preliminary Report Prepared for U.S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-76/21. 127 pp.

Woodward-Clyde Consultants. 1980. Gravel removal studies in arctic and sub-arctic floodplains in Alaska. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/08. 403 pp.

Younkin, W.E. and D.L. Johnson. 1980. The impact of waste drilling fluids on soils and vegetation in Alberta. In Symposium/Research on Fate and Effects of Drilling Fluids and Cuttings. Vol I. pp. 98-113.

Zingula, R.P. 1976. Hearing on proposed oil and gas leasing on the mid-Atlantic outer continental shelf. Atlantic City, New Jersey. 27 pp.

Zinn, J. 1978. Effects on coastal communities. Environmental Planning for Offshore Oil and Gas. Vol. II. U.S. Fish and Wildlife Service. Department of Interior. FWS/OBS-77/13. 60 pp.

Zitko, U. and S. Tibbo. 1971. Fish kill caused by an intermediate oil from coke ovens. In Impact of Oil on the Marine Environment. IMCO/FAO/UNESCO/WMO/IAEA/UN. (1977). Rep. Stud. (6). 250 pp.

References for Inventory Maps

Adams, A.E. 1979. The life history of the snow crab Chionoecetes opilio: a literature review. Alaska Sea Grant Program, Sea Grant Report 78-13. University of Alaska. Fairbanks, Alaska. 141 pp.

Alaska Department of Fish and Game (ADF&G). 1963. Alaska king crab. Commercial Fisheries Division. Anchorage, Alaska. n.p.

Alaska Department of Fish and Game (ADF&G). 1973. Alaska's wildlife and habitat. Vol. I. Anchorage, Alaska. n.p.

Alaska Department of Fish and Game (ADF&G). 1978. Alaska's fisheries atlas. Vol. I. 39 pp. and maps.

Alaska Department of Fish and Game (ADF&G). 1979a. Annual Management Report - Norton Sound - Kotzebue - Port Clarence. Commercial Fisheries Division. Anchorage, Alaska. 150 pp.

Alaska Department of Fish and Game (ADF&G). 1979b. Annual Management Report - Yukon Area. Commercial Fisheries Division. Anchorage, Alaska. 88 pp.

Alaska Department of Fish and Game (ADF&G). 1979c. Survey-Inventory Progress Report - Brown/Grizzly Bear, Game Management Unit 22 - Seward Peninsula. Game Division. Anchorage, Alaska. 5 pp.

Alaska Department of Fish and Game (ADF&G). 1979d. Survey-Inventory Progress Report - Moose, Game Management Unit 22 - Seward Peninsula. Game Division. Anchorage, Alaska. pp. 165-174.

Alaska Department of Fish and Game (ADF&G). 1979e. Survey-Invertory Progress Report - Muskoxen, Game Management Unit 22 - Seward Peninsula. Game Division. Anchorage, Alaska. pp. 194-195.

Alaska Department of Fish and Game (ADF&G). Unpublished data (a). Draft maps of State land resources. Habitat Division. Fairbanks, Alaska n.p.

Alaska Department of Fish and Game (ADF&G). Unpublished data (b). Aerial stream survey data for Norton Sound Management District. Commercial Fish Division. Nome, Alaska. n.p.

Alaska Department of Fish and Game (ADF&G). Unpublished data (c). Draft maps of subsistence data compiled for Norton Sound villages. Subsistence division. Nome, Alaska.

Alaska Department of Fish and Game (ADF&G). Unpublished data (d). Statewide waterfowl harvest data. Game Division. Anchorage, Alaska. n.p.

Alaska Department of fish and Game (ADF&G). Unpublished data (e). Commercial King Crab data - 1977, 1978, and 1979. Commercial Fish Division. Kodiak, Alaska. n.p.

Arctic Environmental Information and Data Center (AEIDC). 1976. Alaska regional profiles: northwest region. Edited by L.L. Selkregg. University of Alaska. Anchorage, Alaska. 265 pp.

Alexander, V. 1980. Ice-biota interactions: an overview (draft). In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce. 27 pp.

Alexander, V. and T. Chapman. 1980. Role of epontic algal communities in Bering Sea ice. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce. 27 pp.

Alt, K.T. 1978. Inventory and cataloging of sport fish and sport fish waters of western Alaska. Federal Aid in Fish Restoration F-9-10. Sport Fish Division. Alaska Department of Fish and Game. Anchorage, Alaska. pp. 36-47.

Alt, K.T. 1979. Inventory and cataloging of sport fish and sport fish waters of western Alaska. Federal Aid in Fish Restoration F-9-11. Sport Fish Division. Alaska Department of Fish and Game. Anchorage, Alaska. pp. 99-121.

Alton, M.S. 1974. Bering Sea benthos as a food resource for demersal fish populations. In Oceanography of the Bering Sea. Edited by D.W. Hood and E.J. Kelley. Institute of Marine Science, University of Alaska. Fairbanks, Alaska. pp. 257-277.

Bakkala, R.G. 1979. Population characteristics and ecology of yellowfin sole. In Fisheries Oceanography-Eastern Bering Sea Shelf. Northwest and Alaska Fisheries Center. National Marine Fisheries Service. Seattle, Washington. 329 pp.

Barton, L.H. 1978. Finfish resource surveys in Norton Sound. In Environmental Assessment of the Alaskan Continental Shelf. Final Reports of Principal Investigators, June 1978. Vol. IV - Biological Studies. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 75-313.

Barton, L.H. and D.L. Steinhoff. 1980. Assessment of spawning herring (Clupea harengus pallasii) stocks at selected coastal areas in the eastern Bering Sea. Division of Commercial Fisheries. Alaska Department of Fish and Game. Juneau, Alaska. Informational Leaflet No. 187. 60 pp.

Bedard, J. 1969. Feeding of the least, crested and parakeet auklets around St. Lawrence Island, Alaska. Canadian Journal of Zoology. 47:1025-1050.

Bockstoce, J. and D. Botkin. 1980. The historical status and reduction of the Western Arctic bowhead whale (Balaena mysticetus) population by the pelagic whaling industry, 1848-1914. In Research Conducted on Bowhead Whales, June 1979 to June 1980: Preliminary Results. J.H. Johnson, H.W. Braham, B.D. Krogman, W.M. Marquette, R.M. Sonntag and D.J. Rugh. 1980. National Marine Mammal Laboratory. NMFS, NOAA. Seattle, Washington. 50 pp.

Braham, H.W., C.H. Fiscus and D.J. Rugh. 1977. Marine mammals of the Bering and southern Chukchi Seas. Marine Mammal Division, NWAFC, NMFS, NOAA. Seattle, Washington. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1977. Vol. I. Receptors: Mammals. NOAA. U.S. Department of Commerce. Boulder, Colorado. 99 pp.

Braham, H.W. and B.D. Krogman. 1977. Population biology of the bowhead (Balaena mysticetus) and beluga (Delphinapterus leucas) whale in the Bering, Chukchi and Beaufort Seas. Marine Mammal Division, NWAFC, NMFS, NOAA. Seattle, Washington. 29 pp.

Braham, H.W., J.J. Burns, G.A. Fedoseev and B.D. Krogman. 1979. Distribution and density of ice-associated pinnipeds in the Bering Sea, April 1976. Draft - submitted to the U.S. - U.S.S.R. Convention on the Environmental Protection of Marine Mammals. National Marine Mammal Laboratory, NWAFC, NMFS, NOAA. Seattle, Washington. np.

Braham, H.W., B.D. Krogman, S. Leatherwood, W. Marquette, D. Rugh, M. Tillman, J. Johnson and G. Carroll. 1979. Preliminary report of the 1978 Spring Bowhead Whale Research Program Results. Rep. Int. Whal. Comm. 29:291-306.

Braham, H., B. Krogman, J. Johnson, W. Marquette, D. Rugh, M. Nerini, R. Sonntag, T. Bray, J. Brueggeman, M. Dahlheim, S. Salvage and C. Goebel. 1980. Population studies of the bowhead whale (Balaena mysticetus): results of the 1979 spring research season. Rep. Int. Whal. Comm. pp. 391-404.

Broad, A.C. 1980. Biological events - October through June - Beaufort Sea. In Arctic Project Bulletin. Special Bulletin No. 29. Arctic Project Office, Outer Continental Shelf Assessment Program. pp. 36-37.

Brower, W.A., H.W. Searby, J.L. Wise, H.F. Diaz and A.S. Prechtel. 1977. Climatic atlas of the outer continental shelf waters and coastal regions of Alaska - Vol. II - The Bering Sea. AEIDC. University of Alaska. Anchorage, Alaska. 443 pp.

Burbank, D.C. 1979. Drift bottle trajectories and circulation in the NE Bering Sea and SE Chukchi Sea. Habitat Division. Alaska Department of Fish and Game. Anchorage, Alaska. 53 pp.

Bureau of Land Management (BLM). 1980. Western Alaska and Bering-Norton petroleum development scenarios: commercial fishing industry analysis. Technical Report No. 51. Alaska Outer Continental Shelf Office. Anchorage, Alaska. 717 pp.

Burns, J.J. 1965. The walrus in Alaska, its ecology and management. Federal Aid in Wildlife Restoration W-6-R-5. Alaska Department of Fish and Game. Juneau, Alaska. 47 pp.

Burns, J.J. 1970. Remarks on the distribution and natural history of pagophilic pinnipeds in the Bering and Chukchi Seas. Journ. of Mammal. 51(3):445-454.

Burns, J.J. and T.J. Eley. 1977. The natural history and ecology of the bearded seal (Erignathus barbatus) and the ringed seal (Phoca hispida). In Environmental Assessment of the Alaskan Continental Shelf. Annual Report - OCSEAP. Vol. I. Receptors: Mammals. NOAA. U.S. Department of Commerce. Boulder, Colorado. 57 pp.

Burns, J. and T. Eley. 1978. The natural history and ecology of the bearded seal (Erignathus barbatus) and the ringed seal (Phoca hispida). In Environmental Assessment of the Alaskan Continental Shelf. Vol. I. Receptors: Mammals, Birds. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 99-160.

Burns, J.J. and K.J. Frost. 1979. The natural history and ecology of the bearded seal, Erignathus barbatus. In Environmental Assessment of the Alaskan Continental Shelf. Final Report - OCSEAP. NOAA. U.S. Department of Commerce. Boulder, Colorado. 77 pp.

Burns, J.J. (In Press). Ice as marine mammal habitat in the Bering Sea. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. NOAA. U.S. Department of Commerce. 40 pp.

Coachman, L.K., K. Aagaard and R.B. Tripp. 1975. Bering Strait: the regional physical oceanography. University of Washington Press, Seattle. 172 pp.

Coachman, L.K., R. Charnell, J. Schumacher, K. Aagaard and R. Muench. 1977. Norton Sound/Chukchi Sea Oceanographic Processes. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1977. Vol. XV - Transport. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 579-673.

Coachman, L.K., and K. Aagaard. 1980. Reevaluation of water transports in the vicinity of Bering Strait: Part I. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In Press). NOAA. U.S. Department of Commerce. Boulder, Colorado. 45 pp.

Divoky, G.J. 1980. Birds and the ice edge ecosystem in the Bering Sea. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce. 15 pp.

Drury, W.H. and B.B. Steele. 1977. Birds of coastal habitats on the south shore of the Seward Peninsula, Alaska. In Environmental Assessment of the Alaskan Continental Shelf. Annual Report of Principal Investigators for Year Ending March 1977. Vol. III. Receptors: Birds. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 1-178.

Drury, W.H., J.O. Biderman, S. Hinckley and J.B. French, Jr. 1978. Ecological studies in the northern Bering Sea: Birds of coastal habitats of the south shore of Seward Peninsula, Alaska. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for Year Ending March 1978. Vol. II. Receptors: Birds. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 510-613.

Drury, W.H. and J.O. Biderman. 1978. Ecological studies in the northern Bering Sea: studies of seabirds in the Bering Strait. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigator for the Year Ending March 1978. Vol. II. Receptors: Birds. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 751-838.

Drury, W.H. and C. Ramsdell. 1979. Ecological studies of birds in the northern Bering Sea: seabirds at Bluff, distribution of birds at sea, movements of birds in the Bering Strait. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1979. Vol. I. Receptors: Mammals, Birds. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 600-769.

Drury, W.H., C. Ramsdell and J.B. French, Jr. 1980. Ecological studies in the Bering Strait Region. College of the Atlantic. Bar Harbor, Maine. Final Report for NOAA-OCSEAP, Research Unit #237. 307 pp.

Dupre, W.R. 1978. Yukon Delta coastal processes study. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1978. Vol. XI - Hazards. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 384-446.

Durham, F.E. 1975. The catch of bowhead whales (Balaena mysticetus) by Eskimos in the western Arctic (unpublished manuscript). In Population Biology of the Bowhead (Balaena mysticetus) and Beluga (Delphinapterus leucas) Whale in the Bering, Chukchi and Beaufort Seas. H.W. Braham and B.D. Krogman. 1977. Marine Mammal Division, NWAFC, NMFS, NOAA. Seattle, Washington. 29 pp.

Eaton, M.F. 1980. United States king and tanner crab fishery in the Eastern Bering Sea. Report to the North Pacific Fishery Management Council. Anchorage, Alaska. 47 pp.

Eisler, D.C. 1978. Subsistence activities in the proposed Bering Land Bridge National Reserve. Anthropology and Historic Preservation Cooperative Park Studies Unit. University of Alaska. Fairbanks, Alaska. 100 pp.

Ellanna, L.J. 1980. Bering-Norton petroleum development scenarios sociocultural systems analysis. Alaska OCS Socioeconomic Studies Program. Technical Report No. 54. Vol. I. Anchorage, Alaska. 455 pp.

Everitt, R.D. and B.D. Krogman. 1979. Sexual behavior of bowhead whales observed off the north coast of Alaska. Arctic. 32(3):277-280.

Fay, F.H. 1957. History and present status of the Pacific walrus population. Trans. N. Amer. Wildl. Conf. 22:431-443.

Fay, F.H. and T.J. Cade. 1959. An ecological analysis of the avifauna of St. Lawrence Island, Alaska. University of California Publications in Zoology. University of California Press. Berkeley and Los Angeles, California. 63(2):73-150.

Fay, F.H. 1961. The distribution of waterfowl to St. Lawrence Island, Alaska. In The Twelfth Annual Report of the Wildfowl Trust. Arctic Health Research Center. Public Health Service. U.S. Department of Health, Education and Welfare. Anchorage, Alaska. pp. 70-80.

Fay, F.H. 1974. The role of ice in the ecology of marine mammals of the Bering Sea. In Oceanography of the Bering Sea. Edited by D.W. Hood and E.J. Kelley. Institute of Marine Science, University of Alaska. Fairbanks, Alaska. pp. 383-399.

Fay, F.H., H.M. Feder and S.W. Stoker. 1977. An estimation of the impact of the Pacific walrus population on it's food resources in the Bering Sea. Institute of Marine Science, University of Alaska. Fairbanks, Alaska. 38 pp.

Feder, H.M. and S.C. Jewett. 1978. Trawl survey of the epifaunal invertebrates of Norton Sound, southeastern Chukchi Sea, and Kotzebue Sound. In Environmental Assessment of the Alaskan Continental Shelf. Final Reports of Principal Investigators. Vol. I - Biological Studies. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 713-769.

Flock, W.L., and J.D. Hubbard. 1979. Environmental studies at the Bering Strait. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for Year Ending March 1979. Vol. I. Receptors: Mammals, Birds. NOAA. U.S. Department of Commerce. pp. 713-769.

Fraker, M.A. 1977. The 1977 whale monitoring program. Mackenzie Estuary, N.W.T. Imperial Oil Ltd.; F.F. Slaney and Co., Ltd., Vancouver, B.C.

Fraker, M.A., D.E. Sergeant and W. Hoek. 1978. Bowhead and white whales in the southern Beaufort Sea. Beaufort Sea Project. Technical Report No. 4. Victoria, B.C. 114 pp.

Frost, K. 1979. Memorandum to Lance Trasky December 13. "Norton Sound Resource Maps."

Gill, R. Jr., C. Handel and M. Peterson. 1978. Migration of birds in Alaska marine habitats. In Environmental Assessment of the Alaskan Continental Shelf. Final Reports of Principal Investigators. Vol. V - Biological Studies. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 245-288.

Gill, R. Jr., and C.M. Handel. 1980. Shorebirds of the eastern Bering Sea. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood. (In press). NOAA. U.S. Department of Commerce. 52 pp.

Goodman, J.R., J.A. Lincoln, T.G. Thompson and F.A. Zeusler. 1942. Physical and chemical investigations: Bering Sea, Bering Strait, and Chukchi Sea during summers of 1937 and 1938. Univ. Wash. Publ. Oceanogr. 3(4):105-169.

Gundlach, E.R., J.L. Sadd, G.I. Scott and D.J. Maiero. (Preliminary data). Shoreline mapping of oil retention risk - Norton Sound. Research Planning Institute. Columbia, South Carolina. (map).

Hart, J.L. 1973. Pacific fishes of Canada. Fisheries Research Board of Canada. Ottawa, Ontario. 740 pp.

Hunt, G.L. Jr., P. Gould, D.J. Forsell and H. Peterson, Jr. 1980a. Pelagic distribution of marine birds in eastern Bering Sea (draft). 93 pp. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce. 92 pp.

Hunt, G.L. Jr., Z. Eppley and W.H. Drury. 1980b. Breeding distribution and reproductive biology of marine birds in the eastern Bering Sea (draft). In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In Press). NOAA. U.S. Department of Commerce. 122 pp.

Hunt, G.L. Jr., G. Sanger, and B. Burgeson. 1980c. Trophic relations of seabirds of the eastern Bering Sea (draft). In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce. 50 pp.

Hunter, R.E., A.H. Sallenger, and W.R. Dupre. 1979. Maps showing directions of longshore sediment transport along the Alaskan Bering Sea coast. USGS. U.S. Department of the Interior. Map MF-1049. 7 pp. and maps.

Interagency Task Group. 1976. Draft Environmental Impact Statement. Consideration of a waiver of the moratorium and return of management of certain marine mammals to the State of Alaska. Vol. I. NOAA, NMFS and Fish and Wildlife Service. Washington, D.C. 123 pp.

Johnson, J.H., H.W. Braham, B.D. Krogman, W.M. Marquette, R.M. Sonntag and D.J. Rugh. 1980. Research conducted on bowhead whales, June 1979 to June 1980: preliminary results. National Marine Mammal Laboratory. NMFS, NOAA. Seattle, Washington. 50 pp.

Jones, R.D. and M. Kirchhoff. 1976. Yukon Delta. U.S. Fish and Wildlife Service, Office of Biological Services. Anchorage, Alaska. 26 pp.

Kenyon, K.W. and D.W. Rice. 1961. Abundance and distribution of the steller sea lion. Journ. of Mammal. 42(2):223-233.

King, J.G. and C.P. Dau. Waterfowl of the eastern Bering Sea (draft). In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce.

Kleinenberg, S.E., A.V. Yablokov, B.M. Bel'kovich and M.N. Tarasevich. 1964. Beluga (Delphinapterus leucas): investigation of the species. Akad. Nauk. SSSR., Moscow (Israel Prog. Sci. Transl., Jerusalem 1969). 376 pp.

Klinkhart, E.G. 1965. The beluga whale in Alaska. Federal Aid in Wildlife Restoration W-6-R and W-14-R. Alaska Department of Fish and Game. Anchorage, Alaska. 11 pp.

Klinkhart, E.G. 1977. A fish and wildlife resource inventory of western and arctic Alaska. Vol. I - Wildlife. Alaska Department of Fish and Game. Anchorage, Alaska. 362 pp.

Krogman, B.D., H.W. Braham, R.M. Sonntag, and R.G. Punsly. 1979. Early spring distribution, density, and abundance of the Pacific walrus (Odobenus rosmarus) in 1976. Final OCSEAP Report No. 14. National Marine Mammal Laboratory, NMFS, NOAA. Seattle, Washington. 47 pp.

Lowry, L.F., K.J. Frost and J.J. Burns. 1978. Food of ringed seals and bowhead whales near Point Barrow, Alaska. Can. Field Nat. 92(1):67-70.

Lowry, L.F., and K.J. Frost. 1979. Feeding and trophic relationships of phocid seals and walruses in the eastern Bering Sea. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce. 35 pp.

Lowry, L.F. and K.J. Frost. (In press). Feeding and Trophic Relationships of phocid seals and walruses in the Eastern Bering Sea. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce.

McLean, R.F., W.A. Bucher, and B.A. Cross. 1977. A compilation of fish and wildlife resources information for the State of Alaska. Vol. 3 - Commercial Fisheries. Compiled by the Alaska Department of Fish and Game under contract to the Alaska Federal-State Land Use Planning Commission. 606 pp.

McLean, R.F. and K.J. Delaney. 1977. A fish and wildlife resource inventory of western and arctic Alaska. Vol. 2 - Fisheries. Alaska Department of Fish and Game. Anchorage, Alaska. 340 pp.

McNutt, S.L. 1979. Remote sensing analysis of ice growth and distribution in the eastern Bering Sea. Pacific Marine Environmental Laboratory. NOAA. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce. 43 pp.

McNutt, S.L. 1981. Ice conditions in the eastern Bering Sea. NOAA Technical Memorandum ERL PMEL-24. NOAA/Pacific Marine Environmental Laboratory. 179 pp.

McPhail, J.D. and C.C. Lindsey. 1970. Freshwater fishes of northwestern Canada and Alaska. Fisheries Research Board of Canada. Bulletin 173. 381 pp.

McRoy, C.P. 1968. The distribution and biogeography of Zostera marina (Eelgrass) in Alaska. Pacific Science. 22(4):507-512.

McRoy, C.P., J.J. Goering, and W.S. Shiels. 1972. Studies of primary productivity in the eastern Bering Sea. In Biological Oceanography of the northern North Pacific Ocean. Edited by A.Y. Takenouti et. al. Idemitsu Shoten, Tokyo. pp. 199-216.

Muench, R.D., R.B. Tripp, J.D. Cline. 1979. Circulation and hydrography of Norton Sound. In Eastern Bering Sea Shelf Oceanography and Resources. Edited by D.W. Hood. (In press). NOAA. U.S. Department of Commerce. .45 pp.

Muench, R.D.. 1980. Physical oceanography and circulation in Norton Sound. Summary of a verbal presentation at the Norton Sound Synthesis meeting held in Anchorage. 28-30 October, 1980. 9 pp.

Neiman, A.A. 1964. Age of bivalve mollusks and the utilization of benthos by flatfishes in the south eastern Bering Sea. In Soviet Fisheries Investigations in the northeast Pacific, Part 3. (Israel Program for scientific Translations, 1968). pp. 191-196.

North Pacific Fishery Management Council (NPFMC). 1980. Draft fishery management plan for king crab in the western Alaskan king crab fishery. Anchorage, Alaska. 66 pp.

Pearson, C.A., H.O. Mofjeld and R.B. Tripp. 1980. Tides of the eastern Bering Sea shelf (draft). In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce. 47 pp.

Pease, C.H. 1979. Eastern Bering Sea ice dynamics and thermodynamics. Pacific Marine Environmental Laboratory. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce. 24 pp.

Pereyra, W.T., J.E. Reeves and R.G. Bakkala. 1976. Demersal fish and shellfish resources of the eastern Bering Sea in the baseline year 1975. Northwest Fisheries Center. NOAA. U.S. Department of Commerce. 618 pp.

Pereyra, Dr. W.T., R.J. Wolotira, Jr., T.M. Sample, and M. Morin, Jr. 1977. Baseline studies of fish and shellfish resources of Norton Sound and the southeastern Chukchi Sea. Annual Report. In Annual Reports of Principal Investigators for the Year Ending March 1977. Vol. VIII. Receptors: Fish, Littoral, Benthos. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 288-319.

Powell, G.C., and R.B. Nickerson. 1965. Reproduction of king crabs *Paralithodes camtschatica* (Tilesius). J. Fish. Res. Bd. Canada. 22(1):101-111.

Ray, V.M., and W.R. Dupre. 1979. The ice-dominated regimen of Norton Sound. Appendix B of Yukon Delta Coastal Processes Study by William R. Dupre. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1979. Vol. IX - Hazards. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 291-320.

Regnart, R.I. and A.P. Kingsbury. 1980. Pacific herring stocks and fisheries the eastern Bering Sea: a report to the Alaskan Board of Fisheries. Commercial Fish Division. Alaska Department of Fish and Game. Anchorage, Alaska. 42 pp.

Reilly, S.B., D.W. Rice and A.A. Wolman. 1980. Preliminary population estimate for the California gray whale based upon Monterey shore censuses, 1967/68 to 1978/79. Rep. Int. Whal. Comm. pp. 359-368.

Reynold, H.V. 1979. NPR-A mammal studies - structure, status, reproductive biology, movement, distribution and habitat utilization of a grizzly bear population in NPR-A. Alaska Department of Fish and Game. Anchorage, Alaska. 41 pp.

Rice, D.W. and A.A. Wolman. 1971. The life history and ecology of the gray whale (*Eschrichtius robustus*). Marine Mammal Biological Laboratory. U.S. Fish and Wildlife Service. Seattle, Washington. 142 pp.

Seaman, G.A. and J.J. Burns. (In press). Preliminary results of recent studies on belukhas in Alaskan waters. Rept. Int. Whal. Comm., SC/32/SM series, 31st. Ann. Rept.

Seaman, G.A. and J.J. Burns. (In prep.). Distribution, abundance, and life history of belukha whales of northern and western Alaska. Alaska Department of Fish and Game. Fairbanks, Alaska.

Seaman, G.A. and L.F. Lowry. (In prep.). Spring and summer foods of belukha whales (*Dephinapterus leucas*) in western Alaska. Alaska Department of Fish and Game. Fairbanks, Alaska.

Sears, H.S. and S.T. Zimmerman. 1977. Alaska intertidal survey atlas. National Marine Fisheries Service. Auke Bay Laboratory. 360 pp.

Selkregg, L.L. 1976. Alaska regional profiles: northwest region. Arctic Environmental Information and Data Center. University of Alaska. Anchorage, Alaska. 265 pp.

Selkregg, L.L. 1976. Alaska regional profiles: Yukon region. Arctic Environmental Information and Data Center. University of Alaska. Anchorage, Alaska. 346 pp.

Sharma, G. 1974. Contemporary depositional environment of the eastern Bering Sea. In Oceanography of the Bering Sea. Edited by D.W. Hood and E.J. Kelley. Institute of Marine Science. Occasional Pub. No. 2. University of Alaska. Fairbanks, Alaska. pp. 517-540.

Sheilds, G.F. and L.J. Peyton. 1978. Avian community ecology of the Akalik-Inglutalik River delta, Norton Bay, Alaska. In Environmental Assessment of the Alaskan Continental Shelf. Final Reports of Principal Investigators March 1979. Vol. V - Biological Studies. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 608-710.

Sowls, A.L., S.A. Hatch, and C.J. Lensink. 1978. Catalog of Alaskan seabird colonies. U.S. Fish and Wildlife Services, Biological Services Program. FWS/OBS - 78/78. 254 pp.

Sparks, A.K. and W.T. Pereyra. 1966. Benthic invertebrates of the southeastern Chukchi Sea. In Environment of the Cape Thompson Region, Alaska. Edited by N.J. Wilimovsky and J.N. Wolfe. U.S. Atomic Energy Commission. Washington, D.C. pp. 817-838.

Stoker, S.W. 1973. Winter studies of under-ice benthos on the continental shelf of the northeastern Bering Sea. M.S. Thesis. University of Alaska. College, Alaska. 60 pp.

Stoker, S.W. (In press). Benthic invertebrate macrofauna of the eastern Bering/Chukchi continental shelf. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce. n.p.

Straty, R.R. 1979. Trans-shelf movements of Pacific salmon. Northwest and Alaska Fisheries Center. Auke Bay Laboratory. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce. 60 pp.

Stringer, W.J. 1978. Morphology of Beaufort, Chukchi and Bering Seas near shore ice condition by means of satellite and aerial remote sensing. In Environmental Assessment of the Alaskan Continental shelf. Annual Reports of Principal Investators for the Year Ending March 1978. Vol. X - Transport. NOAA. U.S. Department of Commerce. Boulder, Colorado.

Stringer, W.J. 1980. The role of sea ice as a physical hazard and a pollutant transport mechanism in the Bering Sea. Geophysical Institute. University of Alaska. Fairbanks, Alaska. 26 pp.

Stringer, W.J. and G. Weller. 1980. Studies of the behavior of oil in ice, conducted by the Outer Continental Shelf Environmental Assessment Program. Arctic Project Office, OCSEAP, University of Alaska. Fairbanks, Alaska. 17 pp.

Takenouti, Y., and D. Hood. 1974. Bering Sea oceanography: an update. Institute of Marine Science. Report No. 75-2. University of Alaska. Fairbanks, Alaska. pp. 39-57.

Takenouti, A.Y., and K. Ohtani. 1974. Currents and water masses in the Bering Sea: a review of Japanese work. In Oceanography of the Bering Sea. Edited by D.W. Hood and E.J. Kelley. Institute of Marine Science. University of Alaska. Fairbanks, Alaska. pp. 39-57.

Tillman, M., J. Breiwick and D. Chapman. (In press). Reanalysis of historical whaling data for the western Arctic bowhead whale population. In Research Conducted on Bowhead Whales, June 1979 to June 1980: Preliminary Results. J.H. Johnson, H.W. Braham, B.D. Krogman, W.M. Marquette, R.M. Sonntag and D.J. Rugh. 1980. National Marine Mammal Laboratory. NMFS, NOAA. Seattle, Washington. 50 pp.

Tomilin, A.G. 1957. Cetacea. In Animals of the U.S.S.R. and adjacent countries. Edited by V.G. Heptner. Akad. Nauk. SSSR, Moscow. Vol. 9. 756 pp.

U.S. Coast Guard (USCG). 1975. Comparison of ecological impacts of postulated oil spills at selected Alaskan locations. Final report: Vol. I. Department of Transportation. Washington, D.C.

U.S. Coast Pilot - 9 (USCP). 1977. Pacific and arctic coasts Alaska: Cape Spencer to Beaufort Sea. NOAA. U.S. Department of Commerce. Washington, D.C. 354 pp.

U.S. Department of the Interior (USDI). 1974. Proposed Yukon Delta national wildlife refuge. Final Environmental Statement. Alaska Planning Group. 550 pp.

U.S. Fish and Wildlife Service (USFWS). 1979. Draft environmental assessment on subsistence hunting of migratory birds in Alaska and Canada. U.S. Department of the Interior. Anchorage, Alaska. n.p.

Waldron, K.D. 1979. Ichthyoplankton. Northwest and Alaska Fisheries Center, National Marine Fisheries Service. In The Eastern Bering Sea Shelf: Oceanography and Resources. Edited by D.W. Hood and J.A. Calder. (In press). NOAA. U.S. Department of Commerce. 66 pp.

Webster, B.D. 1979. Ice edge probabilities for the eastern Bering Sea. NOAA. Technical Memorandum NWS AR-26. AOAA/National Weather Service. Anchorage, Alaska.

Wolotira, R.J., T.M. Sample and M. Morin. 1977. Demersal fish and shellfish resources of Norton Sound, the southeastern Chukchi Sea and adjacent waters in the baseline year 1976. NOAA. U.S. Department of Commerce. Seattle, Washington. 292 pp.

Wolotira, R.J. 1979. Memo to Frank Wendling - National Marine Fisheries Service - regarding BLM-OCS Bering Sea - Norton Sound oil and gas lease sale (Tentative sale #57). n.p.

Wolotira, R.J. Preliminary data from a 1979 trawl survey of Norton Sound.

Zimmerman, S.T., J.H. Gnagy, N.I. Calvin, J.S. Mackinnon, L.Barr, J. Fujioka and T.R. Merrell. 1977. Baseline/reconnaissance characterization, littoral biota, Gulf of Alaska and Bering Sea. Final report. In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1977. Vol. VIII. Receptors: Fish, Littoral Benthos. NOAA. U.S. Department of Commerce. Boulder, Colorado. pp. 1-228.

Personal Communications for Impact Section and Inventory Maps

Alt, K. 1980. Alaska Department of Fish and Game, Fairbanks, Alaska.

Arvey, W. 1980. Alaska Department of Fish and Game, Anchorage, Alaska.

Barto, B. 1981. Crowley Environmental Services. Anchorage, Alaska.

Barton, L. 1980. Alaska Department of Fish and Game. Anchorage, Alaska.

Baxter, R. 1980. Alaska Department of Fish and Game. Bethel, Alaska.

Braham, H.W. 1980. Northwest and Alaska Fisheries Center. Seattle, Washington.

Burns, J.J. 1980. Alaska Department of Fish and Game. Fairbanks, Alaska.

Coachman, L. 1980. University of Washington, Department of Oceanography. Seattle, Washington.

Community of Alakanuk. 1980. Alakanuk, Alaska.

Community of Kotlik, 1980. Kotlik, Alaska.

Community of Koyuk. 1980. Koyuk, Alaska.

Community of St. Michael. 1980. St. Michael, Alaska.

Ellanna, L. 1980. Alaska Department of Fish and Game. Nome, Alaska.

Fay, F.H. 1980. Institute of Marine Science, University of Alaska. Fairbanks, Alaska.

Frost, K.J. 1980. Alaska Department of Fish and Game. Fairbanks, Alaska.

Grauvogel, C.A. 1980. Alaska Department of Fish and Game. Nome, Alaska.

Grundy, S. 1981. Alaska Department of Fish and Game. Fairbanks, Alaska.

Hall, J. 1978. Northern Gulf of Alaska. U.S. Fish and Wildlife Service. Sacramento, California.

Holden, K. 1978. United States Geophysical Survey. Anchorage, Alaska.

Jones, R. 1980. U.S. Fish and Wildlife Service. Anchorage, Alaska.

Jurasz, C. 1978. Sea Search. Juneau, Alaska.

Kawerak Inc. 1980. Native nonprofit Corporation. Nome, Alaska.

Kessel, B. 1980. University of Alaska. Fairbanks, Alaska.

Lensink, C. 1980. U.S. Fish and Wildlife Service. Anchorage, Alaska.

Lowry, L. 1980. Alaska Department of Fish and Game. Fairbanks, Alaska.

Money, D. 1980. U.S. Fish and Wildlife Service. Anchorage, Alaska.

Moulton, L. 1981. Alaska Department of Fish and Game. Anchorage, Alaska.

Nelson, R.R. 1980. Alaska Department of Fish and Game. Nome, Alaska.

Pegau, R. 1980. Alaska Department of Fish and Game. Nome, Alaska.

Pungowiyi, C. 1980. Kawerak, Inc. Nome, Alaska.

Ramsdell, C. 1980. College of the Atlantic. Maine.

Regnart, R. 1980. Alaska Department of Fish and Game. Anchorage, Alaska.

Schaefer, G. 1980. Alaska Department of Fish and Game. Nome, Alaska.

Schneider, K.B. 1978. Alaska Department of Fish and Game. Anchorage, Alaska.

Schwartz, L. 1980. Alaska Department of Fish and Game. Nome, Alaska.

Seaman, G.A. 1980. Alaska Department of Fish and Game. Anchorage, Alaska.

Springer, H. 1980. Alaska Department of Transportation and Public Facilities. Fairbanks, Alaska.

Thomas, D. 1980. Alaska Department of Fish and Game. Nome, Alaska.

Walluk, T. 1980. Alaska Department of Fish and Game. Nome, Alaska.

Wolfson, L. 1980. ARCO Oil and Gas Company. Anchorage, Alaska.

Wolotira, R. 1980. National Marine Fisheries Service. Kodiak, Alaska.

Woodby, D. 1980. Point Reyes Bird Observatory. California.

APPENDIX

A

SPECIES LISTS & TIMING CHARTS

Scientific Names of Species Discussed
on Map 3 - Benthic Invertebrate
Concentrations *

Red King crab	*Paralithodes camtschatica*
Blue king crab	*Paralithodes platypus*
Tanner crab	*Chionoecetes opilio*
Starfish	*Asterias* sp.
Shrimp	*Pandalus goniurus*
Snails	*Neptunea heros*
Clams	*Mya arenaria*
	Macoma calcarea

* Scientific names represent the dominant species within a class grouping, that are present in the Norton Sound - Bering Strait region.

Scientific Names of Species Discussed
on Map 4 - Fish Concentrations

Pacific herring	Clupea harengus pallasi
Chum salmon	Oncorhynchus keta
Pink salmon	Oncorhynchus gorbuscha
King salmon	Oncorhynchus tshawytscha
Sockeye salmon	Oncorhynchus nerka
Coho salmon	Oncorhynchus kisutch
Grayling	Thymallus arcticus
Cisco	Coregonus sp.
Whitefish	Coregonus sp.
Sheefish	Stenodus leucichthys
Capelin	Mallotus villosus
Toothed smelt	Osmerus mordax dentex
Arctic cod	Boreogadus saida
Saffron cod	Eleginus gracilis
Shorthorn sculpin	Myoxocephalus scorpius groenlandicus
Pacific sand lance	Ammodytes hexapterus
Yellowfin sole	Limanda aspera
Longhead dab	Limanda proboscidea
Arctic flounder	Liopsetta glacialis
Starry flounder	Platichthys stellatus
Alaska plaice	Pleuronectes quadrituberculatus

TABLE 41: TIMING OF FISH LIFE HISTORY STAGES OCCURING IN THE NORTHERN BERING SEA AND NORTON SOUND REGION AS DISCUSSED ON MAP 4.

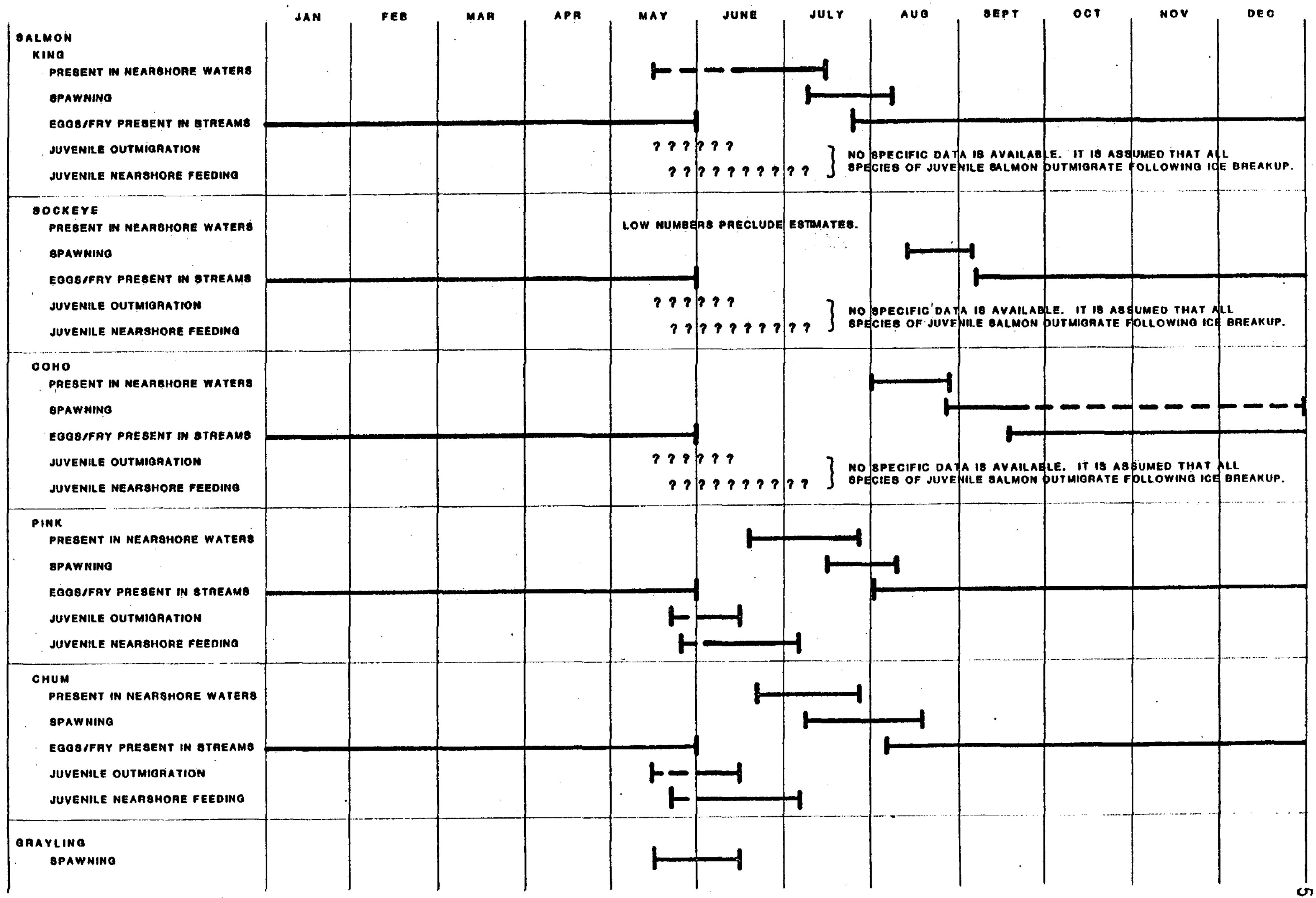
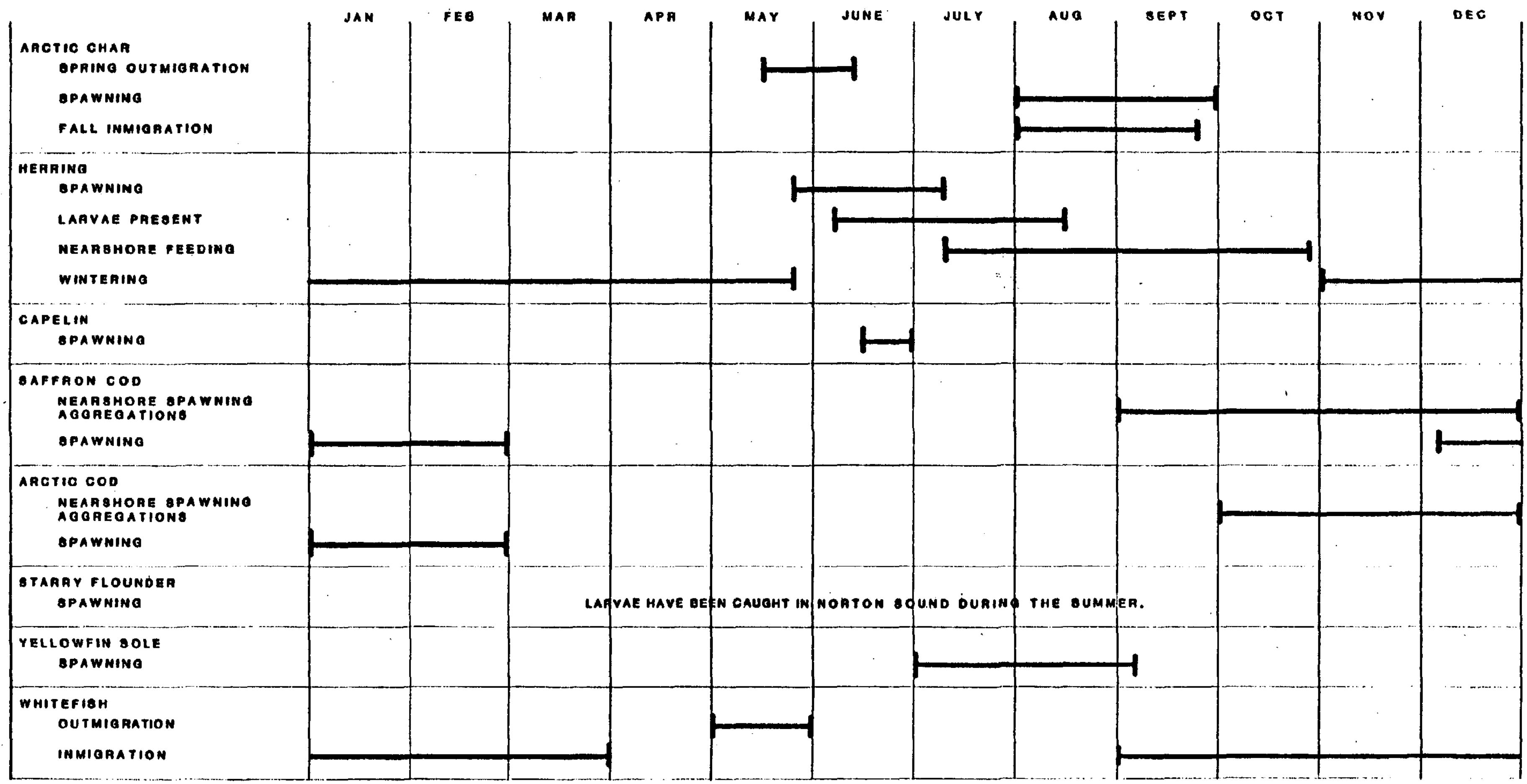


TABLE 41 :(CONT.) TIMING OF FISH LIFE HISTORY STAGES OCCURING IN THE NORTHERN BERING SEA AND NORTON SOUND REGION AS DISCUSSED ON MAP 4.



REFERENCES: A.D.F.&G., 1978; Alt, 1979; Alt, pers. comm.; Bakkala, 1979; Barton, 1980; Frost, 1979; Frost, pers. comm.; McPhail and Lindsey, 1970; Nunam Kitlutsisti, pers. comm.; Schaefer, pers. comm.; U.S. Coast Guard, 1975; Waldron, 1979.

Scientific Names of Species Discussed
on Map 5 - Bird Concentrations

Pelagic cormorant	Phalacrocorax pelagicus
Whistling swan	Olor columbianus
Canada goose	Branta canadensis
Black brant	Branta bernicla
Emperor goose	Philacte canagica
Snow goose	Chen caerulescens
Pintail duck	Anas acuta
Greater scaup	Aythya marila
Oldsquaw	Clangula hyemalis
Harlequin duck	Histrionicus histrionicus
Steller's eider	Polysticta stelleri
Common eider	Somateria mollissima
Gyrfalcon	Falco rusticolus
Peregrine falcon	Falco peregrinus
Sandhill crane	Grus canadensis
American plover	Pluvialis dominica
Black-bellied plover	Pluvialis squatarola
Whimbrel	Numenius phaeopus
Sandpipers	Caldris sp.
Red knots	Caldris canutus
Rock sandpiper	Caldris ptilocnemis
Dunlin	Caldris alpina
Western sandpiper	Caldris mauri
Bar-tailed godwit	Limosa lapponica
Red phalarope	Phalaropus fulicarius
Northern phalarope	Phalaropus lobatus
Glaucous gull	Larus hyperboreus
Herring gull	Larus argentatus
Mew gull	Larus canus
Black-legged kittiwake	Rissa tridactyla
Sabine's gull	Xema sabini
Arctic tern	Sterna paradisaea
Aleutian tern	Sterna aleutica
Common murre	Uria aalge
Thick-billed murre	Uria lomvia
Dovekie	Alle alle
Pigeon guillemot	Cepphus columba
Kittlitz's murrelet	Brachyramphus brevirostris
Parakeet auklet	Cyclorrhynchus psittacula
Crested auklet	Aethia cristatella
Least auklet	Aethia pusilla
Horned puffin	Fratercula corniculata
Tufted puffin	Lunda cirrhata

TABLE 42: TIMING OF BIRD LIFE HISTORY STAGES OCCURING IN THE NORTHERN BERING SEA AND NORTON SOUND REGION AS DISCUSSED ON MAP 5.

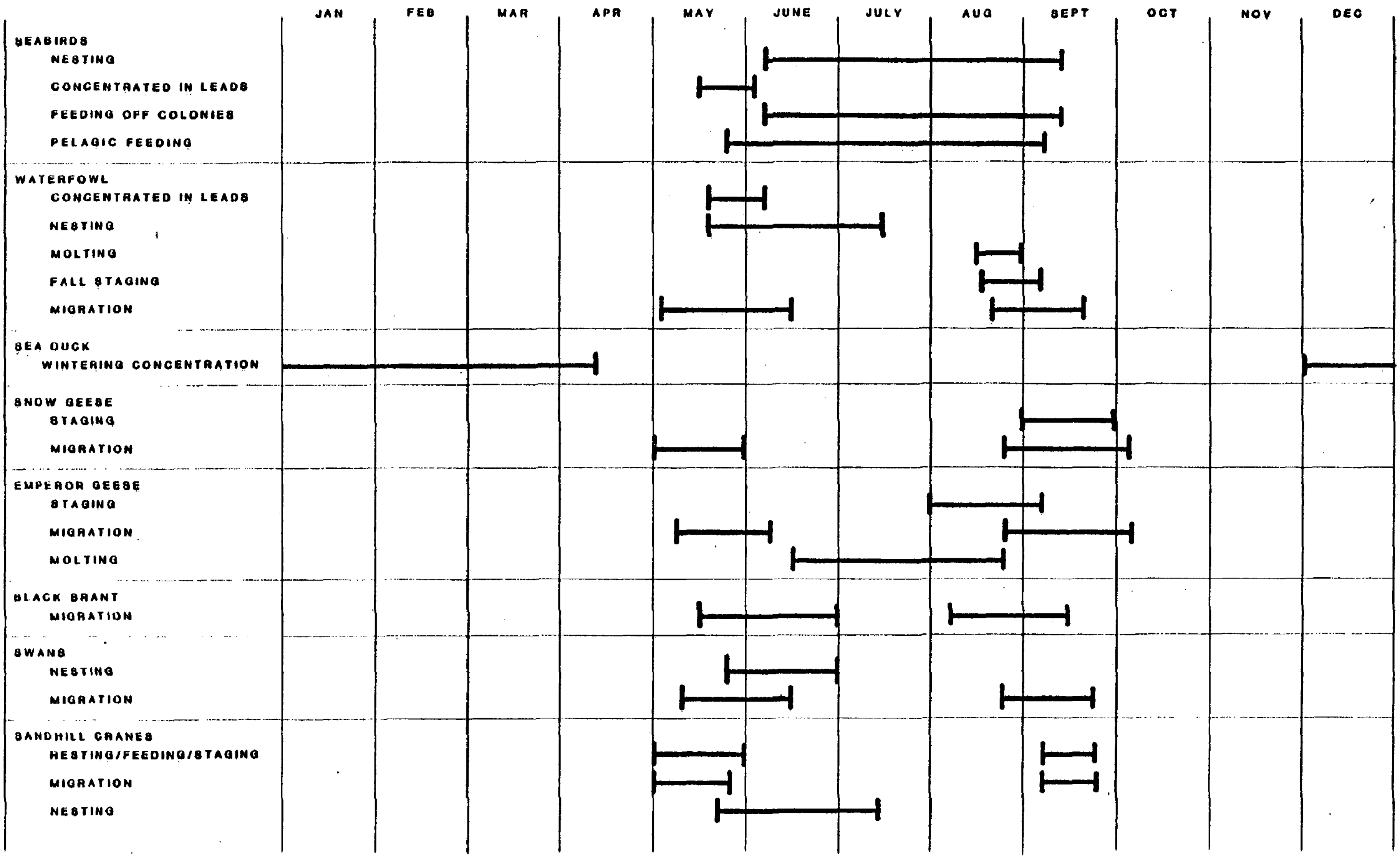
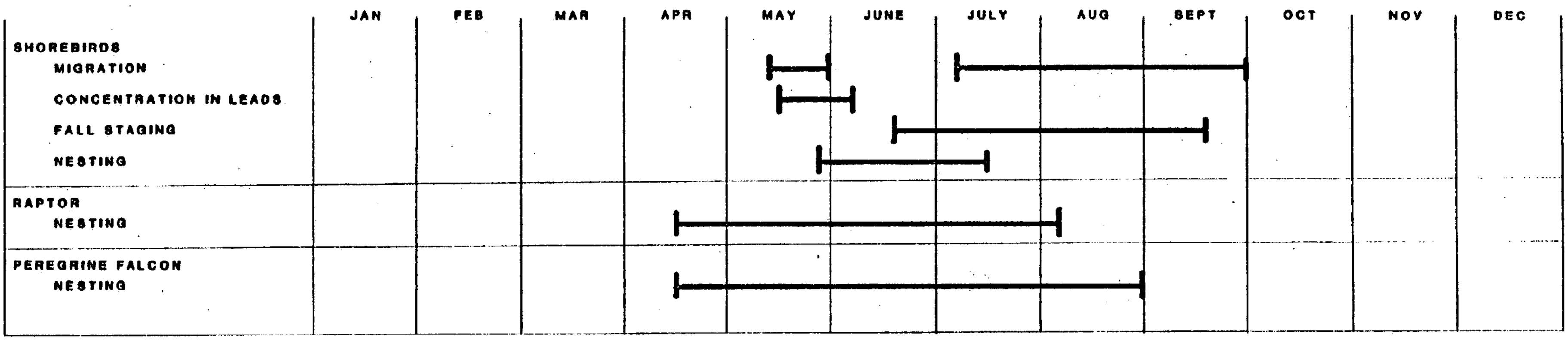


TABLE 42 : (CONT.) TIMING OF BIRD LIFE HISTORY STAGES OCCURING IN THE NORTHERN BERING SEA AND NORTON SOUND REGION AS DISCUSSED ON MAP 5.



REFERENCES: Drury et al, 1978; Drury et al, 1980; Fay, 1961; Flock and Hubbard, 1979; Gill and Handel, 1978; Gill and Handel, 1980; Kessel, pers. comm.; Shields and Peyton, 1978.

Scientific Names of Species Discussed on Map 6 - Marine and Terrestrial Mammal Concentrations - Winter

Bowhead whale	*Balaena mysticetus*
Belukha whale	*Delphinapterus leucas*
Gray whale	*Eschrichtius robustus*
Walrus	*Odobenus rosmarus*
Ringed seal	*Phoca hispida*
Bearded seal	*Erignathus barbatus*
Polar bear	*Ursus maritimus*
Muskox	*Ovibos moschatus*
Moose	*Alces alces*

Scientific Names of Species Discussed
on Map 7 - Marine and Terrestrial
Mammal Concentrations - Summer

Bowhead whale	*Balaena mysticetus*
Belukha whale	*Delphinapterus leucas*
Gray whale	*Eschrichtius robustus*
Killer whale	*Orcinus orca*
Minke whale	*Balaenoptera acutorostrata*
Harbor porpoise	*Phocoena phocoena*
Stellar sea lion	*Eumetopias jubata*
Spotted seal	*Phoca vitulina*
Pacific walrus	*Odobenus rosmarus*
Grizzly bear	*Ursus arctos*
Muskox	*Ovibos moschatus*

TABLE 43 : TIMING OF MAMMAL LIFE HISTORY STAGES OCCURING IN THE NORTHERN BERING SEA AND NORTON SOUND REGION AS DISCUSSED ON MAPS 6 AND 7.

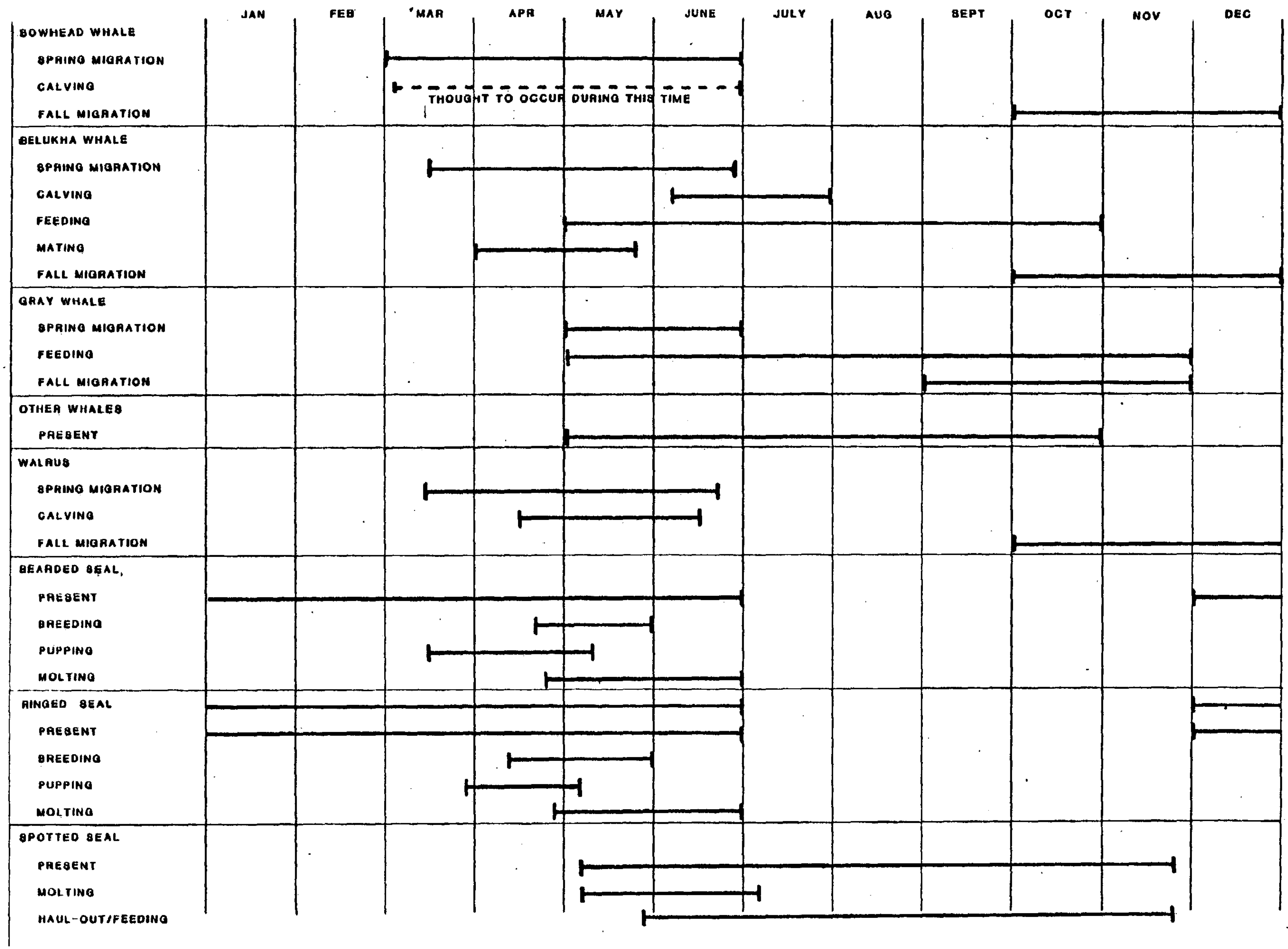
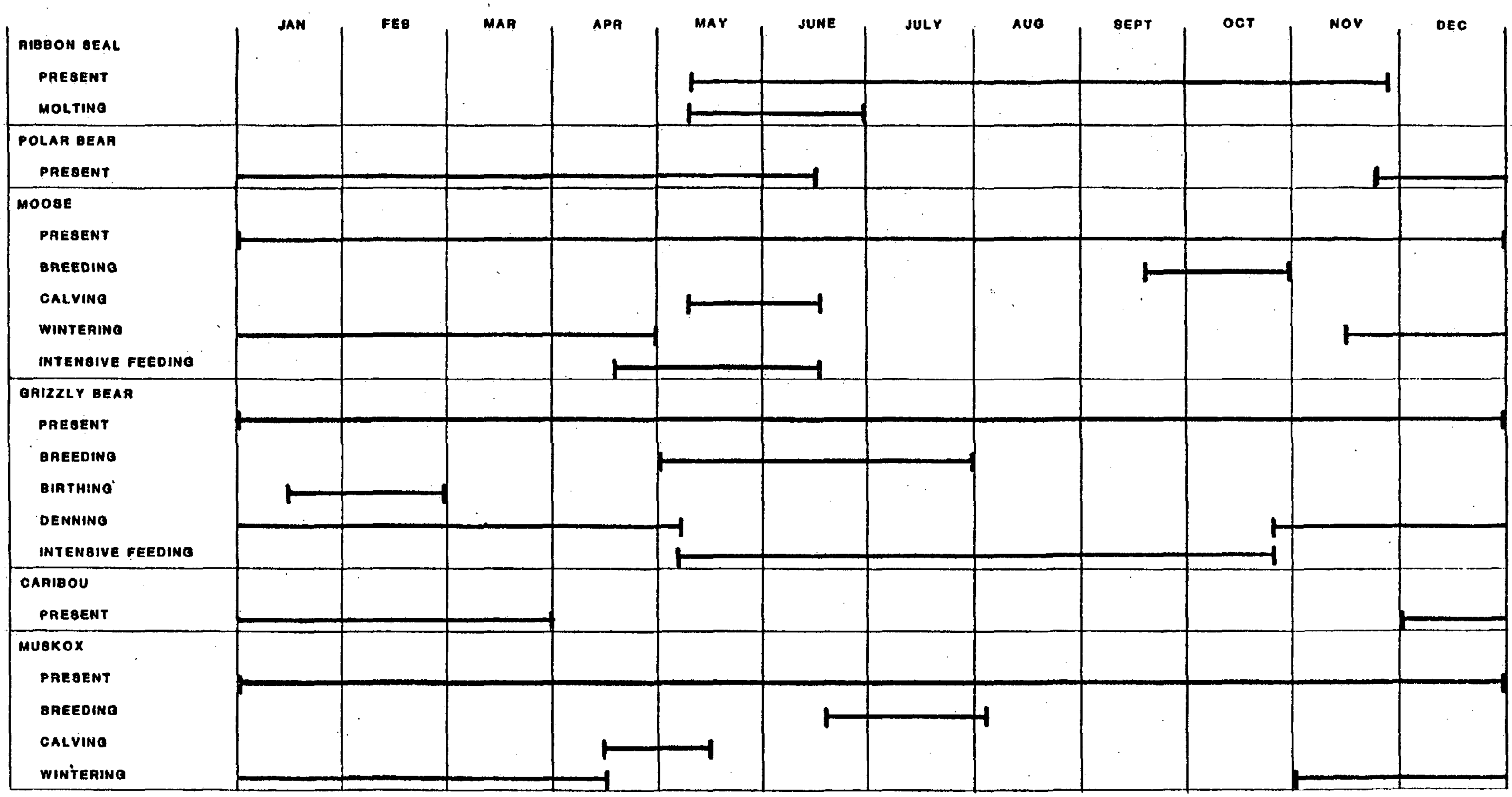


TABLE 43 : (CONT.) TIMING OF MAMMAL LIFE HISTORY STAGES OCCURING IN THE NORTHERN BERING SEA AND NORTON SOUND REGION AS DISCUSSED ON MAPS 6 AND 7.

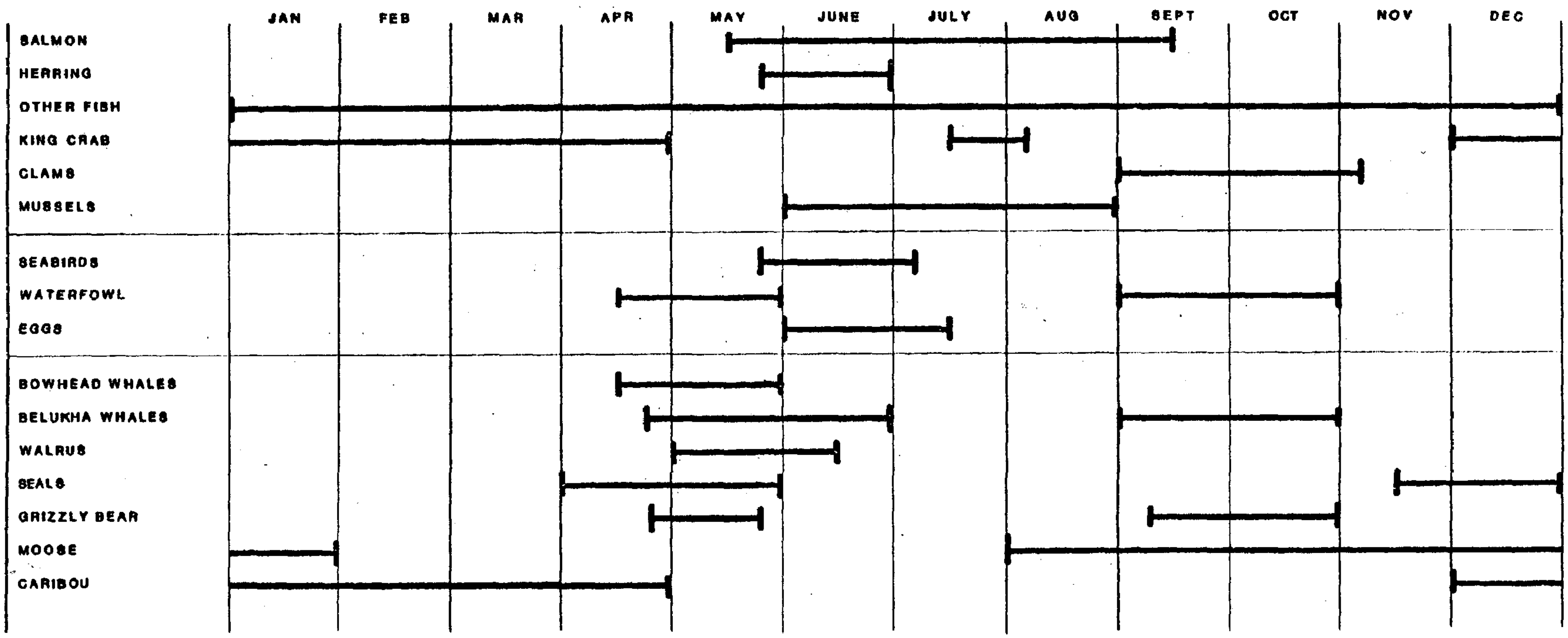


REFERENCES: Braham, pers. comm.; Burns, in press; Fay, pers. comm.; Frost, pers. comm.; Grauvogel, pers. comm.; Kawerak Inc., pers. comm.; Klinkhart, 1977; Rice and Wolman, 1971; Seaman, pers. comm.

Scientific Names of Species Discussed
on Map 8 - Harvest Areas

Belukha whale	Delphinapterus leucas
Bowhead whale	Balaena mysticetus
Bearded seal	Erignathus barbatus
Ringed seal	Phoca hispida
Spotted seal	Phoca vitulina
Pacific walrus	Odobenus rosmarus
Grizzly bear	Ursus arctos
Moose	Alces alces
Caribou	Rangifer tarandus
Salmon	
Chum	Oncorhynchus keta
Pink	Oncorhynchus gorbuscha
Sockeye	Oncorhynchus nerka
Coho	Oncorhynchus kisutch
King	Oncorhynchus tshawytscha
Sheefish	Stenodus leucichthys
Pacific herring	Clupea harengus pallasi
Arctic char	Salvelinus alpinus
Shorthorn sculpin	Myoxocephalus scorpius groenlandicus
Cisco	Coregonus sp.
Grayling	Thymallus arcticus
Whitefish	Coregonus sp.
Burbot	Lota lota
Arctic cod	Boreogadus saida
Saffron cod	Eleginus gracilis
King crab	Paralithodes camtschatica Paralithodes platypus
Freshwater mussels	sp. unknown
Clams	Mya arenaria Macoma calcarea
Common eider	Somateria mollissima
King eider	Somateria spectabilis
Spectacled eider	Lampronetta fisheri
Stellar's eider	Polysticta stelleri
Oldsquaw	Clangula hyemalis
Pintail	Anas acuta
Black brant	Branta bernicla
Snow goose	Chen hyperborea
White-fronted goose	Anser albifrons
Crane	Grus canadensis
Common murre (particularly eggs)	Uria aalge
Thick-billed murre (particularly eggs)	Uria lomvia
Least auklet	Aethia pusilla
Crested auklet	Aethia cristatella
Parakeet auklet	Cyclorhynchus psittacula

TABLE 44 : TIMING OF SUBSISTENCE, COMMERCIAL AND SPORT HARVESTS IN THE NORTHERN BERING SEA AND NORTON SOUND REGION AS DISCUSSED ON MAP 8.



REFERENCES: A.D.F.&G., 1979a, A.D.F.&G., 1979b A.D.F.&G., 1979c, A.D.F.&G., 1980, Burns, 1965, Eisler, 1978, Ellanna, 1980, Ellanna, pers. comm., Grauvogel, pers. comm., Kawerak Inc., pers. comm., Nelson, pers. comm., Seaman, pers. comm., Thomas, pers. comm., Walluk, pers. comm.

B

GLOSSARY

GLOSSARY

AMPHIPOD An organism belonging to the order Amphipoda; individuals lack a carapace, bear unstalked eyes, and respire through gills.

ANADROMOUS Classification of fish that live in the sea, but ascend rivers to spawn in fresh water, e.g., salmon, Arctic char, etc.

ANOXIC The failure of oxygen to gain access to, or to be utilized by, the body tissues. Waters which have become depleted in dissolved oxygen.

ANTIOXIDANT An inhibitor effective in preventing oxidation by molecular oxygen.

AQUATIC PLANTS Plants that grow either floating on the surface, growing up from the bottom of a body of water or growing under the surface of the water.

AQUIFER A water bearing layer of permeable rock, sand, or gravel.

AROMATIC HYDROCARBONS Hydrocarbons containing at least one benzene ring. See Hydrocarbons.

AUFEIS An ice feature that is formed by water overflowing onto a surface, such as river ice or gravel deposits, and freezing, with subsequent layers formed by water overflowing onto the ice surface itself and freezing.

BACTERIOCIDAL Capability to destroy bacteria.

BACTERIOSTATIC Capability to inhibit bacterial growth or metabolism.

BALLAST Seawater which is pumped into the hold of a ship, generally a tanker, used to enhance stability.

BELUKHA WHALE (Beluga whale) Toothed, white whale.

BENTHIC Refers to aquatic bottom-dwelling organisms including: (a) attached animals, such as the sponges, barnacles, mussels, oysters, some worms, and many attached algae; (b) creeping forms, such as insects, crabs, snails, and certain clams; and (c) burrowing forms which include most clams and worms.

BIOTA The flora and fauna of a region.

BIOMASS The amount of living organisms in a particular area, stated in terms of the weight or volume of organisms per unit area, or of the volume of the environment.

BLOWOUT An uncontrolled flow of gas, oil, and other well fluids from a well to the surrounding air or water. A well blows when formation pressure exceeds the pressure being applied to it by the column of drilling fluid.

BLOOM A proliferation of living algae and/or aquatic plants on the surface of water. Blooms are frequently stimulated by phosphate enrichment.

BOOM A floating device that is used to contain oil on a body of water.

BUFFER ZONE A vegetated buffer area that provides erosion control for ongoing construction, adding to site aesthetics and reducing noise levels during construction. Buffer zones are located along water courses and shorelines to trap sediment and pollutants. Width of buffer zones is determined by slope of land, severity of erosion, and vegetation type.

BULKHEAD Structure installed to prevent erosion of land; usually a vertical wall built parallel, or nearly so, to the shoreline.

CARCINOGEN Substance that can cause cancer.

CHEMORECEPTION Reception of a chemical stimulus by an organism.

CHRONIC Marked by long duration or frequent recurrence.

COASTAL ZONE Coastal waters and adjacent lands that exert a measurable influence on the uses of the sea and its ecology.

COMMUNITY Those organisms occupying the same area that make up a naturally occurring assemblage of plants and animals that live in the same environment, are mutually sustaining and interdependent, and are constantly fixing, utilizing, and dissipating energy. The interacting populations are characterized by death and replacement and usually by immigration and emigration of individuals. The populations themselves are always fluctuating with seasonal and environmental changes.

CONTAMINATION To make impure or unclean; an intrusion of or contact with dirt, or foulness from an outside source.

CONTINENTAL SHELF That part of the continental margin that is between the shoreline and the continental slope (or when there is no noticeable continental slope, a depth of 200 m); a shallow submarine plain of varying width forming a border to a continent and typically ending in a steep slope to the oceanic abyss.

COOLING TOWER A device to remove excess heat from water used in industrial operations, notably in electric generators.

COOLING WATERS Waters withdrawn by industrial facilities for the purpose of cooling equipment and then discharged back into a freshwater or marine environment.

COST WELL Continental Offshore Stratigraphic Test well.

CRUDE OIL A comparatively volatile liquid bitumen composed principally of hydrocarbon, with traces of sulfur, nitrogen, or oxygen compounds, (natural gas, petroleum, water) can be removed from the earth in a liquid state.

<u>DEMERSAL</u> Living at or near the bottom of the sea.

<u>DEPURATION</u> To cleanse or purify.

<u>DETRITUS</u> A collective term for loose rock and mineral material that is worn off or removed directly by mechanical means, such as abrasion, and moved from its place of origin. Often contains decaying plant material, bacteria, fungi, and numbers of microscopic animals.

<u>DEWATER</u> The draining or removal of water from an enclosure or channel.

<u>DIATOMS</u> Microscopic, single-celled plants growing in marine or freshwater.

<u>DINOFLAGELLATE</u> A one-celled, microscopic, chiefly marine, flagellated organism which resembles both the animal and plant kingdoms.

<u>DISPERSANT</u> A chemical agent used to break up concentrations of organic material. In cleaning oil spills, dispersants are used to disperse oil from the water surface.

<u>DISSOLVED OXYGEN</u> The amount of oxygen, in parts per million, present in water, now generally expressed in mg/l. A critical factor for fish and other aquatic life, and for self-purification of a surface-water body after inflow of oxygen-consuming pollutants. Abbrev: DO.

<u>DISTURBANCE</u> To destroy the tranquility of, and/or to throw into disorder; a local variation from the average or normal condition; an undesired interference.

<u>DIURNAL TIDE</u> A tide in which there is only one high water and one low water each lunar day.

<u>DRAINAGE (AREA)</u> The entire area drained by a river or system of connecting streams such that all streamflow originating in the area is discharged through a single outlet.

<u>DREDGING</u> A method for deepening streams, swamps, or coastal waters by scraping and removing materials from the bottom.

<u>DRILL CUTTINGS</u> Composed of bottom sediments and pieces of pulverized rock from underlying geologic formations and are discharged into marine or fresh water during well drilling.

<u>DRILLING MUDS</u> Special mixtures of clay, water, (or oil) and chemicals which are circulated into the drilling hole to cool and lubricate the drill bit, to remove formation cuttings from the hole, and to prevent blowouts by holding back formation pressures exerted by oil and gas accumulations.

DROGUE A current measuring assembly consisting of a weighted current cross, sail or parachute, and an attached surface buoy. Also known as a drag anchor; sea anchor.

EBB TIDE The reflux of the tide toward the sea; the tide which is at ebb or a state of decline.

ECOLOGY The study of the relationships between organisms and their environments, including the study of communities, patterns of life, natural cycles, relationships of organisms to each other, biogeography, and population changes.

ECOSYSTEM A functional ecological system that includes the organisms of a natural community together with their environment.

EFFLUENTS The liquid waste from sewage and industrial processing discharged into the environment. Generally used in regard to discharges onto land or into waters.

EMULSION A suspension of small globules of one liquid in a second liquid with which the first will not mix.

ENHANCE To increase or make greater, as in value, beauty or abundance.

ENTRAINMENT A process where aquatic organisms (such as plankton, fish, and larval stages of shellfish) are exposed to heat, shock, turbulence, and abrasion as they are drawn in with waters used to reduce waste heat produced by various industrial processes.

ENVIRONMENT The sum of all external conditions and influences (e.g., temperature, light, water, and other organisms) affecting the life, development and ultimately, the survival of the organism.

EPIBENTHIC Animals living on the surface of the bottom substrate.

EPONTIC ALGAE Algae typically planktonic in form, growing in close association with sea ice.

EROSION The weathering and displacement of rock and soils by the force of moving water, ice, wind, and gravity.

ESTUARIES Areas where fresh waters meet salt waters. For example; bays, mouths of rivers, salt marshes and lagoons containing a salinity greater than 0.5 ppt. (parts per thousand) during any portion of the year. Estuaries are delicate ecosystems; they serve as nurseries, spawning areas, and feeding grounds for a large segment of marine life, and provide shelter and food for birds and wildlife.

ESTUARINE Pertaining to, formed, or living in an estuary; especially in the context of deposition and the sedimentary or biological environment of an estuary.

EYRIE The nest of a raptor.

FAST ICE Ice which is held in postion by contact with or attachment to the shore or bottom. It is called "ice foot" if frozen to the shore, "shore ice" if cast onto the shore or beached, "stranded ice" if grounded, and "bottom ice" if frozen to the bottom. Ice which is not in contact with or attached to the shore or bottom is called "floating ice."

FAUNA The entire animal population of a given area.

FEEDSTOCK Natural gas liquids and refinery products, such as naphtha and gas oil, used by petrochemical plants to produce several hundred intermediate and final products, including ammonia, ethane, argon, hydrogen gas, fertilizers, neoprene rubber, aromatics, and ethylene.

FILLING Taking materials produced by dredging and depositing them for fill; or the disposal of by-products. The process of depositing dirt and mud in marshy areas to create more land for real estate development. Filling can disturb natural ecological cycles. See dredging.

FLUSHING The rate at which the water of an estuary is replaced (usually expressed as the time for one complete replacement).

FOOD WEB A modified food chain that expresses feeding relationships at various levels.

FORMATION WATERS Waters discharged from offshore drilling platforms or onshore treatment facilities which are contaminated with hydrocarbons, heavy metals, and hydrogen sulfides which may pollute marine and freshwater environments.

FRY Recently hatched fish.

GAMETES A mature germ cell (an egg or sperm or one of their anticedent cells).

GEOPHYSICAL Dealing with the physics of the earth including the fields of meterology, hydrology, oceanography, seismology, volcanology, magnetism, radioactivity, and geodesy.

GROIN A wall or barrier built outward from the shoreline to trap sand, influence current, deflect waves, or otherwise protect the beach. Syn: jetty.

GROUNDWATER All subsurface water, especially that part that is in the zone of saturation.

GYRE A current moving in a closed, circular system.

<u>HABITAT</u> The part of the physical environment in which a plant or animal lives; the total sum of environmental conditions of a specific place that is occupied by an organism, a population, or a community.

<u>HAUL OUT</u> Resting, molting, pupping or rearing area; or behavior performed by marine mammals in order to get out of the sea and onto a land mass, rock, or ice formation.

<u>HEAVY METAL</u> A metal whose specific gravity is approximately 5.0 or higher e.g. lead, zinc, mercury, nickel etc.

<u>HERBICIDE</u> A chemical used to destroy or inhibit the growth of certain plants.

<u>HIGH-WATER CHANNEL</u> A channel that is dry most of the ice-free season, but contains flowing water during floods.

<u>HYDROCARBON</u> One of a very large group of chemical compounds composed only of carbon and hydrogen; the largest source of hydrocarbons arise from petroleum crude oil.

<u>HYDROSTATIC</u> The condition in which there are equal compressive stresses or equal tensile stresses in all directions, and no shear stresses on any plane.

<u>IMPACT</u> The force of impression of one thing on another; an impelling or compelling effect; the total effect of an environmental change, either natural or man-made, on the ecology of the area.

<u>IMPINGEMENT</u> Entrapment on the protective screens of water-intake structures.

<u>INFAUNA</u> Those aquatic animals that live within, rather than on, the bottom sediment.

<u>INGESTION</u> The act or process of taking food and/or other substances into the animal body.

<u>IN SITU</u> In the original location.

<u>INTERSTITIAL</u> Of, pertaining to, or situated in a space between two things, as in spaces between gravel.

<u>INTERTIDAL AREA</u> The area between the extreme high and low tide levels.

<u>JET</u> A hydraulic device operated by pump pressure for cleaning mud pits and tanks on a rotary drilling location.

<u>JETTY</u> A barrier built outward from the shore into a body of water to influence the current or tide, or to protect a harbor or shoreline. Syn: groin.

LAGOON A relatively shallow estuary exhibiting restricted exchange with the sea. A shallow stretch of seawater, such as a sound, channel, bay, or salt-water lake, which is near or communicating with the sea and partly or completely separated from it by a low, narrow, elongate strip of land, such as a reef, barrier island, sandbank, or spit.

LANDFALL The point at which an offshore pipeline comes onshore.

LARVA The pre-adult form in which some animals hatch from the egg; capable of existing by itself, though usually in a way different from the adult, usually incapable of sexual reproduction and distinctly different from sexually mature adult in form. Turns into adult, usually by a metamorphosis, e.g., tadpole to frog, caterpillar to butterfly etc. Many marine invertebrates have planktonic, transparent, ciliated larvae. Plural: larvae.

LEAD Linear cracks separating bodies of ice.

LNG Liquified natural gas.

MACROALGAE Algae that can be observed with the naked eye.

MACROPHYTE A plant, especially aquatic plants, that can be observed with the naked eye.

MEROPLANKTON An organism that is temporarily planktonic, e.g., eggs and larvae.

MITIGATION Cause to become less harsh or hostile, alleviate, make less severe.

MOLT To shed part or all of a coat or outer covering, such as hair, feathers, shell, horns, or an outer layer of skin, which is replaced periodically by a new growth.

n.mi. Nautical mile. 1.151 miles or 1.852 kilometers. A unit of distance used for sea and air navigation.

NUTRIENT A nutritive substance or ingredient which provides nourishment; elements or compounds essential as raw materials for an organisms growth and development, for example, carbon, oxygen, nitrogen, and phosphorus.

OCS Outer Continental Shelf. See Continental Shelf.

OFFSHORE (a) Situated off of, or at a distance from the shore; submerged zone of variable width extending from the breaker zone to the seaward edge of the continental shelf where substantial movement of material is limited. The offshore zone is seaward of the inshore zone or the shoreline, although it is often regarded as the zone extending seaward from the low-water shoreline. (b) Pertaining to a direction seaward or lakeward from the shore; e.g., an offshore wind or one that blows away from the land, or an offshore current or one moving away from the shore.

ORGANISM An individual constituted to carry out all life functions, any living human, plant, or animal.

PATHOGEN A disease - producing agent; usually refers to living organisms.

PELAGIC (a) Pertaining to the water of the ocean as an environment. (b) Said of marine organisms (such as birds, mammals, and fish) whose environment is the open ocean, rather than the bottom or shore areas. (c) Also refers to fish which do not spend their whole life on the bottom, although they may remain fairly near the shore, such as herring or sardines.

PETROCHEMICAL A chemical isolated or derived from petroleum or natural gas.

PHEROMONE Intraspecific behavior inducing substance.

PHOTO-OXIDATION A chemical reaction induced by light which increases the oxygen content of a compound.

PHYTOPLANKTON That part of the plankton composed of floating, microscopic aquatic plants. See Plankton.

PILINGS Long, slender columns usually of timber, steel, or reinforced concrete, driven into the ground to carry a vertical load.

PLANKTON Animals and plants of the sea or a lake which float or drift almost passively. They are usually very small. Plankton occur mainly near the surface, where plants get sufficient light, and are of great ecological and economic importance, providing food for fish and whales.

PLUME Effluent material at the mouth of an outfall which is present in the receiving waters before mixing reduces them below a detectable level.

POLLUTANT Any introduced gas, liquid, or solid that makes a resource unfit for a specific purpose.

POLLUTION Making something physically impure or unclean; to contaminate the environment especially with man-made waste.

POLYCHAETES A class of segmented marine worms.

POLYNYA Open water area surrounded by ice.

POTAMODROMOUS Fish which occupy the slow moving, warmer portion of rivers below the leadwaters but upstream from any saltwater or brackish water.

PPM Parts per million; can be stated as mg/l.

PREDATION A mode of life in which food is primarily obtained by the killing and consuming of animals.

RECEIVING WATERS Rivers, lakes, oceans, or other bodies that receive treated or untreated waste waters.

REFINERY A building and equipment used for refining or purifying a crude substance, such as oil.

RIP A body of water made turbulent by the convergence of opposing tides, currents, or winds; a current of water agitated by passing over an irregular bottom.

RIPARIAN Living or located on the bank of a river, pond, or small lake.

RIPRAP A large, durable layer of broken stones erected in water or soft ground as a foundation to prevent erosion.

RUNOFF That portion of rainfall, melted snow, or irrigation water that flows across the ground surface and eventually is returned to streams. Runoff can pick up pollutants from the air or the land and carry them to the receiving waters.

SACRIFICIAL BEACH A beach designed to protect an artificial island through gradually sloping (1:20 underwater slope) beaches which force waves to break and dissipate their energy before they reach the island. The beach is replenished as necessary by additional dredging.

SALINITY A measure of the quantity of dissolved salts in sea water in parts per thousand of water.

SEDIMENT Fragmental material, or a mass of such material, either organic or inorganic, transported by, suspended in, or deposited by air, water, or ice. It ultimately forms in layers on the earth's surface in an unconsolidated form; e.g., sand, gravel, silt, mud, till, loess, alluvium. In the singular, it refers to material suspended in water or recently deposited. In the plural, it refers to deposits of unconsolidated materials.

SEDIMENTATION The act or process of accumulating sediments in layers.

SESSILE Permanently attached to the substrate.

SCOUR The removal of sediments by running water, usually associated with removal from the channel bed or floodplain surface.

SILT CURTAINS A flexible barrier erected around a source of silty water which is designed to allow the sediment to settle out before allowing it to enter a relatively clean body of water.

SILTATION The deposition or accumulation of stream-deposited silt that is suspended in a body of standing water.

SKIMMER A mechanical device for removing oil or scum from the water.

<u>SKIMMER WALL</u> A wall in front of a water intake structure designed to prevent clogging by material floating on the surface. Especially to prevent clogging by floating ice.

<u>SLUMP</u> A type of landslide characterized by the downward slipping of a mass of rock or unconsolidated debris.

<u>SMOLT</u> A young salmon that is roughly 2 years old, at the stage of development when it assumes the silvery color of the adult.

<u>SOLUBLE</u> Capable of being dissolved

<u>SPOIL</u> Earth and rock excavated or dredged.

<u>SPRAY POND</u> An arrangement for cooling large quantities of water in open reservoirs or ponds; nozzles spray a portion of the water into the air for the evaporative cooling effect.

<u>STAGING</u> The grouping of waterfowl and seabirds for feeding and resting before, during, and after migration.

<u>STAGING AREA</u> An area of staging activities. See Staging.

<u>STAMUKHI</u> Large piles of ice formed on tidal flats from beach ice broken free and deposited higher on the flats. Usually frozen to the underlying mud.

<u>SUBSTRATE</u> The base on which an organism lives.

<u>SUSPENSION</u> The state of a substance when its particles are mixed with, but remain undissolved in a fluid or solid.

<u>TANKER</u> A cargo boat fitted with tanks for carrying liquid in bulk.

<u>THALWEG</u> The line following the lowest part of a valley, whether under water or not; also usually the line following the deepest part or middle of the bed or channel of a river or stream.

<u>THERMAL POLLUTION</u> Degradation of water quality by the introduction of a heated effluent. Primarily a result of the discharge of cooling waters from industrial processes, particularly from electrical power generation. Even small deviations from normal water temperatures can affect aquatic life. Thermal pollution usually can be controlled by cooling towers.

<u>TIDEFLATS</u> Unvegetated sandy or muddy areas exposed at low tide that support worms, crabs, and clams which feed at high tide and retreat into burrows during low tides. High tides also bring juvenile and even adult fish to graze on exposed food supplies. Millions of microorganisms in tideflats serve as natural filters for cleaning polluted water.

TOLERANCE The physiological, behavioral, or ecological limits (e.g., of salinity, temperature, competition, predation) within which living organisms interact with their environment.

TOXIC Relating to a poisonous substance which after discharge and upon exposure, ingestion, inhalation, or assimilation can cause death or disease.

TROPHIC Of or pertaining to food or feeding.

TROPHIC LEVEL A position or level in the food chain determined by the number of energy transfer steps to that level and based on feeding relationships among species.

TURBIDITY Reduced water clarity resulting from the presence of suspended particles, such as silt or finely divided organic matter.

TURNING BASIN An open area at the end of a canal or narrow waterway to allow boats to turn around.

UPWELLING Welling up; moving or flowing upward.

VOLATIZATION The conversion of a chemical substance from a liquid or solid State of a gaseous or vapor State.

WASTE WATER Water carrying wastes from homes, businesses, and industries, that is a mixture of water which supports dissolved or suspended solids.

WETLANDS Includes lands shallowly submerged by water with a frequency and duration sufficient to support, vegetation typically adapted for life in saturated soil conditions. Wetlands are not strictly limited to the zone daily inundated by the tides, but rather are characterized as marshes, bogs, or muskegs which generally have an extensive freshwater zone above sea level and which often have a tidally influenced saltwater zone at sea level.

ZOOPLANKTON Animal life of the plankton. Planktonic animals that supply food for fish. See Plankton.

NOAA COASTAL SERVICES CENTER LIBRARY
3 6668 14103 8010